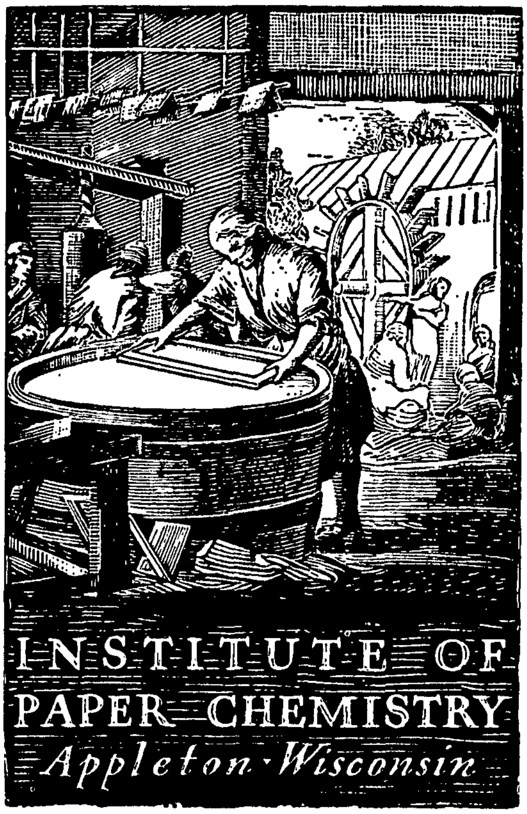

BARK AND WOOD PROPERTIES OF PULPWOOD SPECIES AS RELATED TO SEPARATION AND SEGREGATION OF CHIP/BARK PULPWOOD

Project 3212

Report Seven
A Progess Report
to
MEMBERS OF THE INSTITUTE OF PAPER CHEMISTRY

September 30, 1976

THE INSTITUTE OF PAPER CHEMISTRY

Appleton, Wisconsin

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SUMMARY

American sycamore has a wood specific gravity of 0.45 and an average bark specific gravity of 0.60. Bark extractives levels average 8.1%. Morphologically, the bark contains large numbers of sieve cells, some sclereids but no fiber. Pulping sycamore bark gave a solids yield of 31.4%. Screening the bark resulted in 99% of the solids passing through the 100-mesh screen. Based upon these results, it appears bark would have little influence on the pulp produced from a chip mixture. Hammermilling resulted in a 45% reduction in bark with a 7% wood loss. Water flotation also worked well with this species with segregation possible at moisture contents between 30 and 90% (ovendry basis).

Yellow poplar, based upon values in the literature and measurement data obtained from trees sampled as part of the project, has an average wood specific gravity of 0.39 and a bark specific gravity of 0.38. Extractives levels for wood and bark were 3.9 and 13.8%, respectively. Pulping yellow poplar bark produced a solids yield of approximately 32%. Screening the bark resulted in 13 grams of fiber being produced for every 100 grams of bark pulped. Segregation through water flotation is not possible for this species and hammermilling tests also gave poor results with only a 23% reduction in bark levels and a 7% wood loss. However, compression debarking worked well with this species and a useful approach might be a "screening-compression debarking-rescreening" procedure.

Black tupelo was found to have a wood specific gravity of 0.52 and a bark specific gravity of 0.40. Extractives levels were 3.0 and 10.6%, respectively, for the wood and bark. The bark, when pulped, had a solids yield of approximately

31%. Screening the bark gave very different results for the two trees investigated, with the amount of fiber being produced ranging from 1.4 to 10.5%. Compression debarking has some merit with this species but our hammermilling results were also quite variable. Bark removal ranged from 23 to 54% and, in addition, the hammermilled bark of the two trees was very different in appearance. Segregation through water flotation does not appear possible with this species.

White ash has a wood specific gravity of 0.57 and a bark specific gravity of 0.48. Extractives levels were 4.0 and 12.6%, respectively, for the wood and the bark. Morphologically, the bark contains mostly fiber and sieve cells. Pulping white ash bark gave a solids yield of approximately 36%. Screening the pulp resulted in 16% phloem fibers and <1% sieve cells remaining on the 60- and 100-mesh screens. Hammermilling resulted in only a 24% reduction in bark levels and a 6% wood loss but a useful approach might be to make a quick segregation by screening, hammermilling the fractions high in bark and rescreening. Water flotation is also a feasible technique for this species with segregation possible at moisture contents of between 60 and 110% (ovendry basis).

Added again in this report is a section giving the Btu's, ash, calcium and silica levels for all 28 species investigated thus far. Other added features include the results of segregation of wood/bark mixtures through a chip shredding technique and a table giving the modulus of elasticity for all species investigated.

INTRODUCTION

The APA-TAPPI Ad Hoc Committee on Whole-Tree Utilization, at their recent meeting in Raleigh, North Carolina, reconfirmed by their actions and comments that bark removal, although important, is presently less of a problem than the removal of grit. Most grit becomes part of the chip/bark mixture as a result of harvesting and chipping operations. A high percentage of the grit is associated with the bark while the remainder becomes embedded or otherwise attached to the wood during chipping operations.

There are a number of procedures being proposed for upgrading whole-tree chip quality. Present harvesting methods dictate that the most promising approach must <u>now</u> be the one that removes both bark and grit. The word "now" is emphasized because, as stressed in the Introduction of Progress Report Six, researchers in this field have been shooting at a moving target when it comes to judging the success of a particular method. Our results on bark specific gravity, bark strength, and bark toughness suggest that, of the methods being proposed, the approaches that seem to have the greatest promise for the greatest number of species are the procedures that take advantage of the differences in specific gravity, strength and toughness between bark and wood. Our research in this area indicates there would be a considerable economic advantage to a procedure that dries the whole-tree chips to about 30 to 40% moisture content, then screens out with a considerable tumbling action, the small-sized chip fraction (less than 3/8 inch). This fraction has been shown to be high in bark and, if handled properly when dry, will not only contain a high percentage of the total grit problem but will have a considerable fuel value. The large-size chips, which for most species can be expected to make up 75 to 80% of the total input, will have 4-5% or less bark and only a minor amount of abrasive material. It is suggested that such large-sized chips should be pulped without further treatment other than the reduction of the influence of bark by mixing them with conventional bark-free chips, as the end product demands. The best approach for upgrading the small-sized chips (less than 3/8 inch) would involve a mechanical treatment (modified shredding or hammermilling procedure) that takes advantage of the lower strength and toughness of the bark, as compared to the wood. The approach being suggested would be to mechanically treat and screen the small-size chips and thus decrease the bark and grit content of this fraction to a point that it was acceptable for linerboard and similar quality products.

Our measurements on the characteristics and strength properties of bark indicate a modified shredding/screening procedure will be most successful with those species with high bark specific gravity and low bark strength and low toughness. In hardwoods, when high bark strength and toughness are the result of relatively large numbers of bark fibers, which is often the case, bark removal is expected to be less successful. This, however, would be less serious in view of the useful fibers produced from the stringy, fiber-rich bark.

The four species researched and described in the report that follows, (sycamore, yellow poplar, black tupelo, and white ash) further substantiate the relationship described above. Use of the basic bark data provided should make it possible to determine which of the 32 species under investigation can be most effectively handled by the above procedure. The fuel value information provides a basis for determining the energy value of the rejected bark and wood and the pulping results and the ash content data make it possible to estimate the consequences of pulping the bark remaining in the chips going to the digester.

TREE GROWTH AND BARK DEVELOPMENT

Tree growth and bark development were covered in Project 3212, Progress Report One. To briefly summarize, a tree grows through elongation and enlargement of the bole and crown (primary growth) and thickening of the bole (secondary growth). The bark consists of the inner bark (secondary phloem), which is partly physiologically active, and the outer bark, which is mainly functionless. Tissues in the inner bark are constantly being developed and the first-formed layers of periderm may be cut off from the vital processes of the tree. This can result in roughened bark which may either be cast off or retained as in the case of deeply fissured trees. In smooth-barked trees the first-formed periderm may persist for many years. Figure 1, taken from Chang (1) illustrates the tissues found in different kinds of bark and is provided, along with the Glossary, to help the reader better understand the bark descriptions that follow.

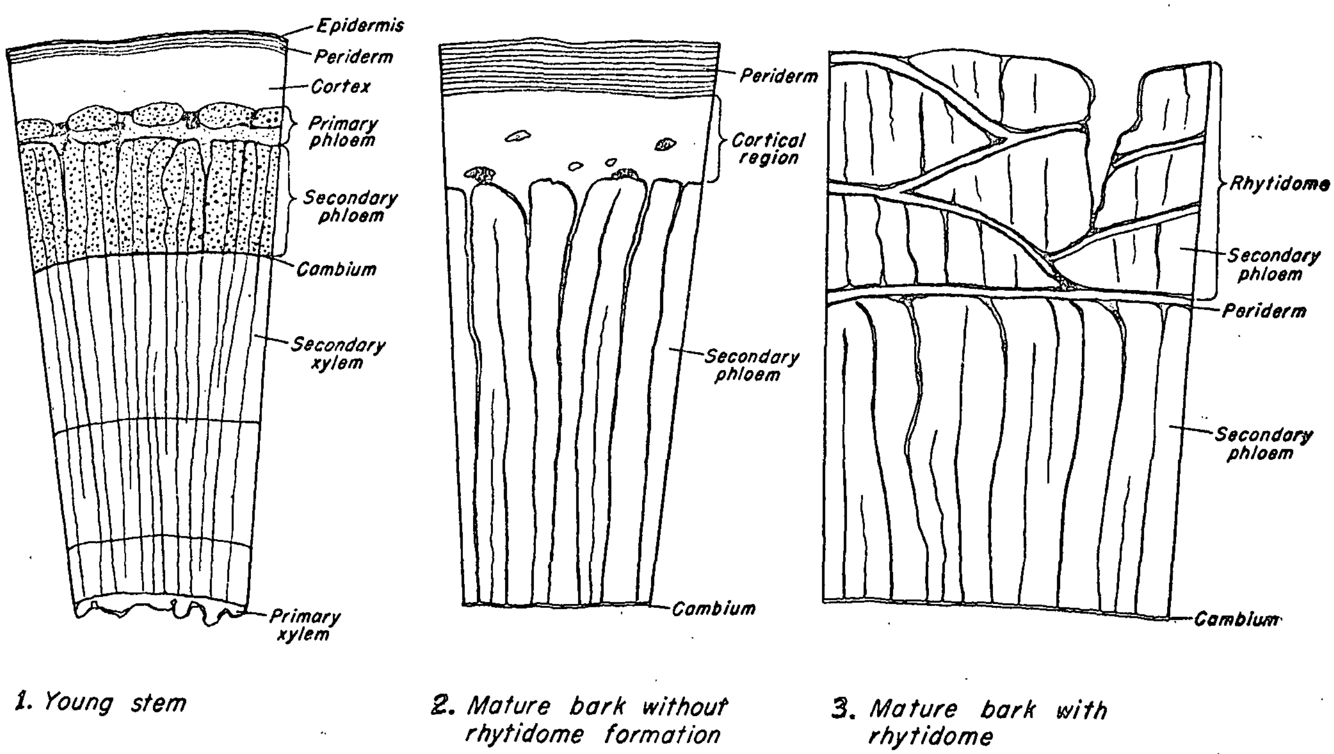


Figure 1. Diagrammatic Drawings Showing the Main Tissue in Different Types of Bark. (1) Cross Section of Young Branch or Stem. (2) Cross Section of Bark Having Persistent Cortex, such as that in the Middle-aged Balsam Fir and Quaking Aspen. (3) Mature Bark with Rhytidome Formation

EXPERIMENTAL PROCEDURES

The experimental procedures employed have, as much as possible, been standardized and the same methods used for each tree species. Progress Report One should be referred to for complete descriptions of the experimental procedures used.

Tree size and sample location were standardized and utilized trees 7 to 9 inches in diameter at breast height (4-1/2 feet). All measurements were made on samples from the breast high location or from 12 to 18-inch bolts obtained from the area just below the breast high sample.

Specific gravity was determined using a water displacement technique that is a modification of the TAPPI Standard Method, T 18 m-53, and results are expressed in terms of ovendry weight/green volume. The bark micropulping procedure was that of Thode, et al. (2). After micropulping, the bark was rinsed, fiberized in a Waring Blendor and decanted on a sintered glass funnel. It was then put through a series of screens and the material on each screen examined for the type of cellular material it contained.

The wood/bark adhesion method measured shear parallel to the grain on a small, specially prepared sample using the Instron tester. Representative growing and dormant season adhesion samples were immersed in ethyl alcohol immediately after testing for later morphological examination.

Bark strength measurements were made using essentially the same procedure as used in measuring wood/bark adhesion (shear parallel to the grain). Bark toughness measured the energy required to rupture a small bark or wood sample by bending with a force parallel to the diameter of the tree. A "Micro Pulverizer" was modified to provide a hammermilling test on standard bark and wood chips. After the chips were fed through the pulverizer, they were separated on a series of soil screens and the percentage on each screen calculated.

Basic density of standard wood and bark chips at various moisture contents was determined using a pycnometer and the chemical, heptane, as the displacement medium. Moisture content was calculated as (wet wt.-o.d. wt.)/o.d. wt. Density was calculated as $(\underline{c} \cdot \underline{d})/[\underline{c}-(\underline{b}-\underline{a})]$ where:

$\underline{a}$ = weight of pycnometer + heptane

$\underline{b}$ = weight of pycnometer + heptane + chip

$\underline{c}$ = weight of chip (wet — before being placed in heptane)

$\underline{d}$ = density of heptane.

BARK AND WOOD PROPERTIES OF AMERICAN SYCAMORE
(*Platanus occidentalis* L.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

American sycamore is widely distributed in the eastern United States, occurring in all states east of the Great Plains except Minnesota. As a north temperate species, the natural range is limited in the north by cold temperatures and in the west by the dry climate of the plains. Tolerant of wet soil, sycamore makes its best growth in alluvial soils where there is a good supply of ground water. Good growth seldom occurs on old eroded field sites although sometimes excellently stocked natural stands appear on the coal-stripped land of the central states. Such sites in the northeast and central states are recommended for plantings. Sycamore sprouts readily from young stumps and cuttings root easily. As a fast-growing tree throughout its life and windfirm due to a strongly branched root system, the American sycamore grows to a larger diameter than any other American hardwood. Sycamores may exceed 10 ft. in diameter and 140 ft. in height although 2-3 ft. diameters of mature trees are common.

WOOD AND BARK MORPHOLOGY

Wood

Sycamore wood ranges in color from light yellow to reddish brown. Although the sapwood is not always distinguishable from the heartwood, the sapwood is generally white to light yellow and the heartwood, light brown to dark, or reddish brown. In wood characteristics sycamore is intermediate when compared with other hardwoods and has an average sp. gr. of about 0.49 at 15% moisture content. Growth rings are distinct, delineated by a narrow band of light-colored tissue at the outer margin. Pores are small, indistinct and frequently crowded. Darker than the rest of the wood, sycamore rays are comparatively wide and quite uniform in width.

The xylem is composed of vessels, fibers, rays and parenchyma. Vessels, numbering 100-140 per sq. mm, average 0.63 mm in length with the largest having diameters of 60-100 microns. Vessels occupy approxiately 51.9% of the total wood volume and the moderately thick-walled fibers, about 28.9%. Fibers are 20-36 µm in diameter and average 1.08 mm in length with a standard deviation of 0.17. Rays are homogeneous, unstoried and 1-14 seriate, up to 3 mm in height along the grain. Longitudinal parenchyma are present as paratracheal and metatracheal-diffuse. The paratracheal are restricted to occasional cells, never forming a sheath. The metatracheal are abundant, scattered and zonate in short lines which exhibit no regularity.

Bark

Bark of the American sycamore has a characteristically mottled appearance caused by the irregular exfoliation of large thin flakes of the outer bark exposing the brown, green and white inner bark. On young branches the bark is thin and creamy white but soon turns brown. At the base of large trees, the bark becomes thick, dark brown and furrowed forming broad scaly ridges. Low winter temperatures may injure the cork cambium and cause the outer bark to slough off, but the tree health is not affected. The barks of the two sycamore trees examined in this project were visually quite different. This carried through in percentages of inner and outer bark with 3212-110 averaging 51% inner bark and 3212-114 averaging 79% inner bark of the total bark by weight. The bark of tree 3212-114 had the typical-looking mottled appearance while tree 3212-110 had a dark brown, furrowed bark such as is found on the base of large trees. Figure 2 illustrates a cross section of inner and outer bark. Appendix Table XXXI describes the trees used in this study.

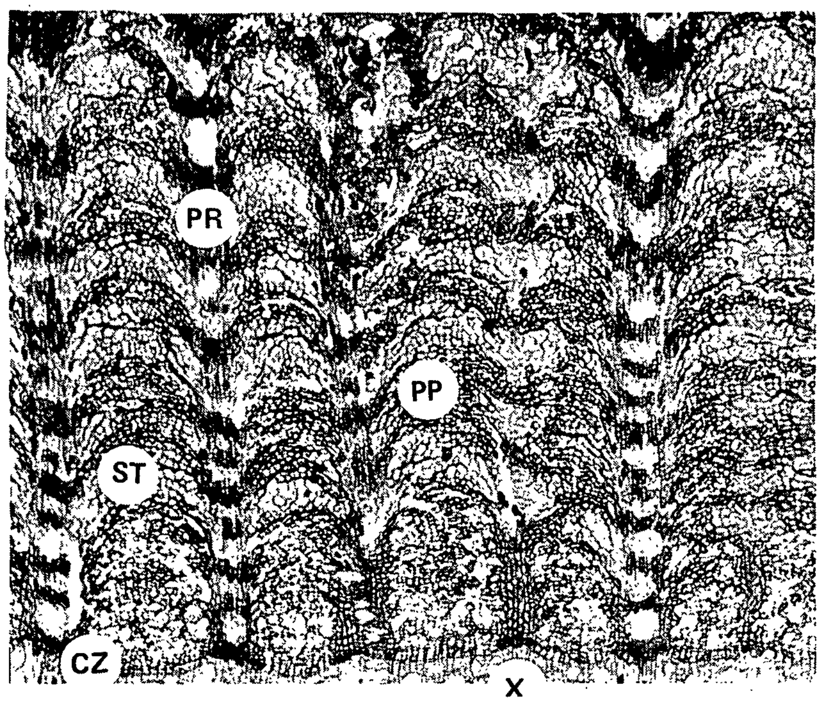


Figure 2. Cross Sections of Sycamore. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Sieve Tubes (ST), Bands of Phloem Parenchyma (PP), and Phloem Rays (PR). Photomicrograph on Top is a Cross Section of Part of the Outer Bark Showing Periderm Layers (P). Magnification — 30X

Anatomical Structure of Bark

The usually thin rhytidome caused by the frequent exfoliation has been attributed to a separation between the thin and thick-walled phellem or cork cells of the periderm. The last-formed periderm usually consists of 3-5 layers of phelloderm, a layer of phellogen and 10 or more layers of phellem. The phelloderm cells are quite uniformly thick walled, rectangular in shape and contain "resinous" substances. Just outside the layer of phellogen are usually 3-5 layers of phellem cells with unevenly thick walls forming a narrow and eccentric cell cavity and showing conspicuous lamellate layers, simple pits and cell contents. These cells are structurally similar to the phelloderm except the latter are relatively smaller and narrower and the cell walls are evenly thickened and lignified rather than suberized. The other form of phellem tends to be more square shaped and has much thinner, but evenly thick walls, no pits and large empty cell cavities. The transition between the two phellem types is usually abrupt although there may be 1-2 layers of an intermediate form.

The secondary phloem consists of sieve tubes, parenchyma, sclerenchyma (sclereids), and phloem rays. Sieve tubes, confined by the broad phloem rays and tangentially aligned parenchyma, retain their shape and size only in groups close to the cambium, becoming deformed and crushed at the third or fourth zone beyond. They appear solitary or in short radial rows and are usually about 40-60 µm in tangential diameter and vary between 420-820 µm in length with a mean length of 634 µm. Companion cells about the same length or less are associated at the narrow dimension of sieve tube elements. Phloem parenchyma form sporadic strands which are usually concentrated in narrow tangential bands. Parenchyma cells continguous with the phloem ray cells merge with them and a tangential zone of phloem rays line up with the parenchyma bands. Individual cells are rectangular in cross section, vary from 50-150 µm high and contain tanniferous substances.

Sclereids are formed from parenchyma strands and ray cells as their cell walls become strongly "lignified" and often uneven in thickness. Between the rays, sclereids form broad bands squeezing the functional elements to a narrow zone, and within the ray, begin at the central portion, forming zones. These lignified cells, sclereids, often contain solitary crystals (probably calcium oxalate) and usually retain their original size and shape but often tend to expand and deform at the outer part of the secondary phloem. Phloem rays are usually high and broad, homogeneous multiseriate rays, about 10-16 cells wide, with a few uniseriate rays. The ray cells are procumbent and square in shape and those at the margins of the rays and in the narrow zones associated with the parenchyma bands are parenchymatous in nature and contain tanniferous substances. The lignified cells begin very close to the cambium in the central portion of the rays and broad sclerified zones alternate with those of the parenchymatous ray cells.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of morphological elements such as sclereids, phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Wherever possible, data on bark have been compared with similar information on wood.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark mixtures.

Specific Gravity

Table I summarizes the information available on wood and bark of sycamore. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of sycamore at several moisture contents.

TABLE I

SYCAMORE SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood	Bark			Reference and
Av.	Inner	Outer	Total	Remarks
0.46				Isenberg (3)
0.46				IUFRO (4)
0.43				Barker (5)
0.50 (sapwood) 0.50 (heartwood)	0.64	--	0.64	IPC 3212-110
0.40 (sapwood) 0.40 (heartwood)	0.57	--	0.57	IPC 3212-114
			0.39[a]	Harkin and Rowe (6)
0.54[a]				Isenberg (3)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.45 appears appropriate for the wood of sycamore. Our samples were divided into heartwood and sapwood and specific gravity determinations made on each. Our limited data show heartwood and sapwood to be approximtely equal in specific gravity.

The specific gravity of the total (inner + outer) bark of sycamore is somewhat higher than that of the wood. Specific gravity determinations could not be made on the outer bark because of its thinness. Inner bark specific gravity was similar to that of the total bark on the samples we examined. Overall values suggested for use in species comparisons are 0.45 for wood and 0.60 for both inner and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists on alcohol-benzene extractives levels of sycamore wood but much less is known about bark extractives levels. Table II summarizes existing data and includes the two IPC trees examined. Sycamore wood is low in extractives and a level of 2.2% is suggested for use in between-species comparisons.

Extractives work done on sycamore bark in this project plus an additional value showed an average level of 8.1%. This is a relatively low level and indications are that extractives are not expected to be a serious problem when pulping the bark of this species.

TABLE II

SYCAMORE ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	1.33	Fengel and Grosser (7)
Wood	1.6	Barker (5)
Wood	3.5	IPC 3212-110
Wood	2.4	IPC 3212-114
Bark	8.1	Harkin and Rowe (6)
Bark	9.3	IPC 3212-110
Bark	7.0	IPC 3212-114

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

As a check on pulp yield and the nature of the material produced from sycamore, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table III summarizes the somewhat unique results of this investigation. Micropulping of sycamore bark resulted in a yield of 29.0 to 33.8% solids. When

TABLE III

SYCAMORE MICROPULPING INVESTIGATIONS

Data	Sample No. 3212-110	Sample No. 3212-114	Remarks[a]
Yield, % solids	29.0	33.8	
Fraction			
on 60 mesh, %	0.09	0.36	Because of the small amount of material retained on the screen totally, nothing can be determined from this fraction.
on 100 mesh, %	0.04	0.17	Same as "on 60 mesh" comments.
on 150 mesh, %	0.4	0.44	The fraction contained principally sieve tubes (90-95%), peridermal and parenchymatous cells (<5%) and a trace of crystalliferous parenchyma (<1%).
on 200 mesh, %	1.4	1.1	The fraction contained principally sieve tubes (70-80%), with small percentages of peridermal and parenchymatous cells (5-10%), crystalliferous parenchyma (<5%) and sclereids (<5%).
through 200 mesh, %	98.1	97.9	The fraction contained principally peridermal and parenchymatous cells (90-95%) with small percentages of crystalliferous parenchyma (5-10%) and sieve tubes (<5%).

[a]Percentages in each fraction on a weight basis.

screened, the coarse screens (60- and 100-mesh) retained very little material (0.33 gram). This appeared to consist of a minor amount of contamination and possibly a few sieve tubes. The on 150-mesh screen contained principally sieve tubes (90-95%) but even this screen retained only 0.4 gram of material. The on 200-mesh screen contained principally sieve tubes (70-80%) with small percentages of peridermal and parenchymatous cells (5-10%). The through 200-mesh screen contained principally peridermal and parenchymatous cells (90-95%). The material passing through this screen amounted to 98%. From these results, it seems likely that very little bark would remain in the pulp even if all the bark was pulped with the wood. There is no fiber in sycamore bark. Figure 3 illustrates the type of material on the 150-mesh screen. Other researchers (8-11) have found that quality pulp can be produced from short-rotation sycamore chipped with bark attached. This agrees with our results which show sycamore bark having little influence on the pulp produced from a chip mixture.

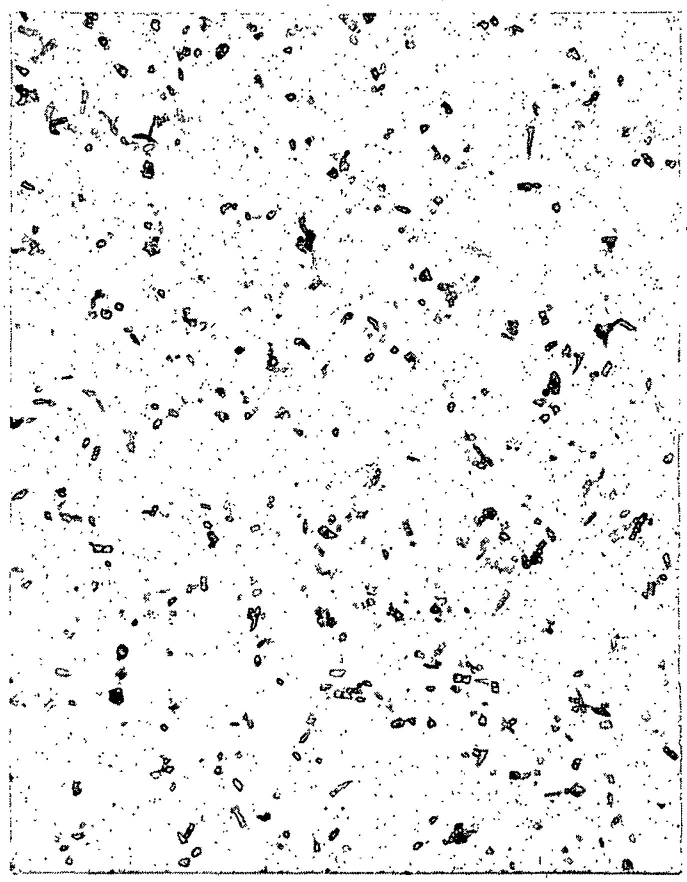


Figure 3. The 150-Mesh Screen Contained by Weight Principally Sieve Tubes (90-95%) with Small Percentages of Peridermal and Parenchymatous Cells (<5%) and a Trace of Crystalliferous Parenchyma (<1%). Magnification — 30X

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for sycamore samples collected March 1 (dormant season). Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly formed xylem elements just outside the cambium zone.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure.

All sycamore samples failed in tensile during adhesion testing. This means that, before failure could occur in the area between the cuts, the samples snapped at the point where the cuts were made. An average value of 14.8 kg/cm^2 was obtained, meaning that it was at that point the sample failed in tensile. Wood/bark adhesion values, if they could have been obtained, would have been higher than this value.

As a result of measurement data taken on the species included in Appendix Table XXXII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. Since sycamore bark doesn't contain fiber, it is possible that the broad phloem rays and the bands of lignified phloem parenchyma contributed to the strength of the bond between wood and bark in this particular instance. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table IV summarizes the bark strength and toughness tests made on the wood and bark of sycamore. (Appendix Tables XXXIV and XXXV compare the modulus of elasticity of sycamore bark with other species examined in this project.)

TABLE IV

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF SYCAMORE[a]

Material	Strength	Toughness
Wood	--	0.50
Inner bark	6.1	0.15
Outer bark[b]	--	--

[a]Determinations average of two trees for toughness and based upon one tree (3212-110) for inner bark strength.
[b]Outer bark too thin to test.

Bark strength values for sycamore inner bark (based on one tree) were intermediate compared to other hardwoods tested thus far. No outer bark tests could be made because of the thinness of the outer bark. Toughness values for both wood and bark were also intermediate compared to other hardwoods tested. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removed by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the relatively high specific gravity of the bark and its intermediate strength and toughness measurements, it appears that hammermilling or other mechanical separation and segregation would work fairly well on sycamore.

Summarized in Table V are the results of the hammermilling tests run on sycamore wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a relatively high reduction in levels of bark, as predicted by the bark strength and toughness tests. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 7% wood loss and a 45% reduction in levels of bark. This is a high reduction in bark compared to many of the other hardwoods investigated thus far. A larger amount of bark could be removed by only retaining the material on the 10-mesh screen but the wood loss would also be greatly increased (63% bark removal and 11% wood loss). This wood loss might be acceptable, however, in view of the reduced bark levels in the chips and the fuel value of the wood. Figure 4 illustrates the effect of hammermilling on wood and bark of sycamore. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It is also possible improvements could be made in screening results by taking advantage of the differences in configuration of wood

TABLE V

SUMMARY OF HAMMERMILLING TEST ON SYCAMORE

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-110	Bark	6.2	29.5	19.2	8.9	17.0	19.2	Inner bark and outer bark tended to stay attached in larger meshes; however, fines appeared to be mostly inner bark.
	Sapwood	75.5	12.4	3.3	2.3	1.8	4.7	
	Heartwood	82.9	8.2	2.6	1.6	1.3	3.4	
3212-114	Bark	3.4	35.4	17.1	7.9	8.8	27.5	Outer bark stays attached to inner bark. Outer bark very thin layer.
	Sapwood	76.3	13.6	3.3	1.8	1.8	3.2	
	Heartwood	72.0	16.9	4.2	1.4	1.8	3.7	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

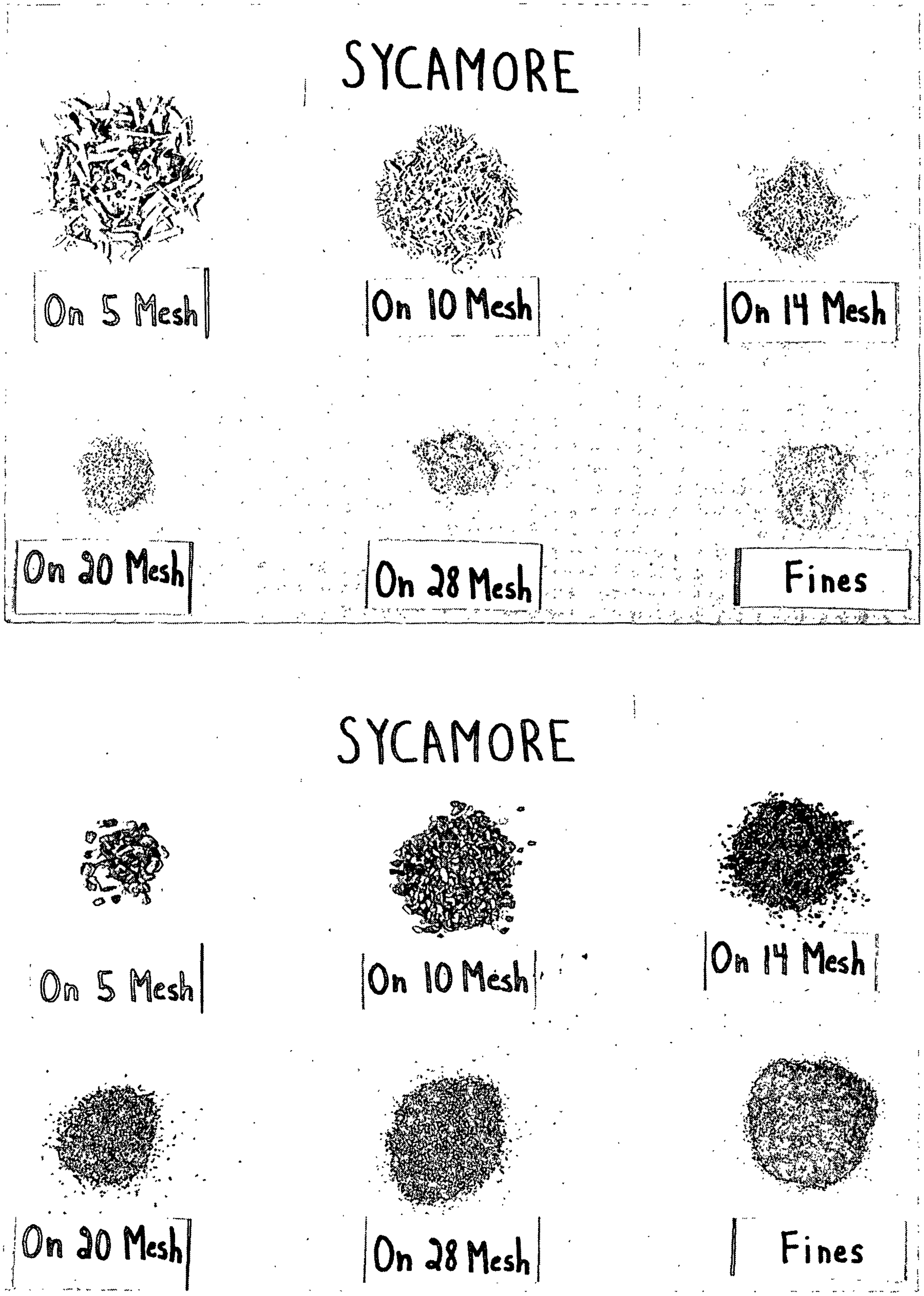


Figure 4. Illustrated is the Effect of Hammermilling on Sycamore Wood (Top) and Bark (Bottom)

and bark chips evident in Fig. 4 (12-13). This would require changes in screen design. Summary Table XXX compares bark strength, toughness and reaction to hammermilling of sycamore with other species tested thus far. The section on "Shredding of Chip/Bark Mixtures" compares hammermilling with shredding for both red pine and northern white oak.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two sycamore trees (IPC

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

3212-110 and IPC 3212-114) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark for 3212-110 had a density similar to that of the total bark, especially at moisture contents under 50%. The inner bark for 3212-114, however, was considerably higher in density than the total bark. Outer bark samples could not be tested for either tree due to thinness and brittleness.

Figure 5 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that at moisture contents of between 30 and 90% (o.d. basis) most bark chips could be expected to sink (density greater than 1). Wood chips, on the other hand, would float (density less than 1). Based upon these results, segregation through water flotation appears to be a feasible method for sycamore.

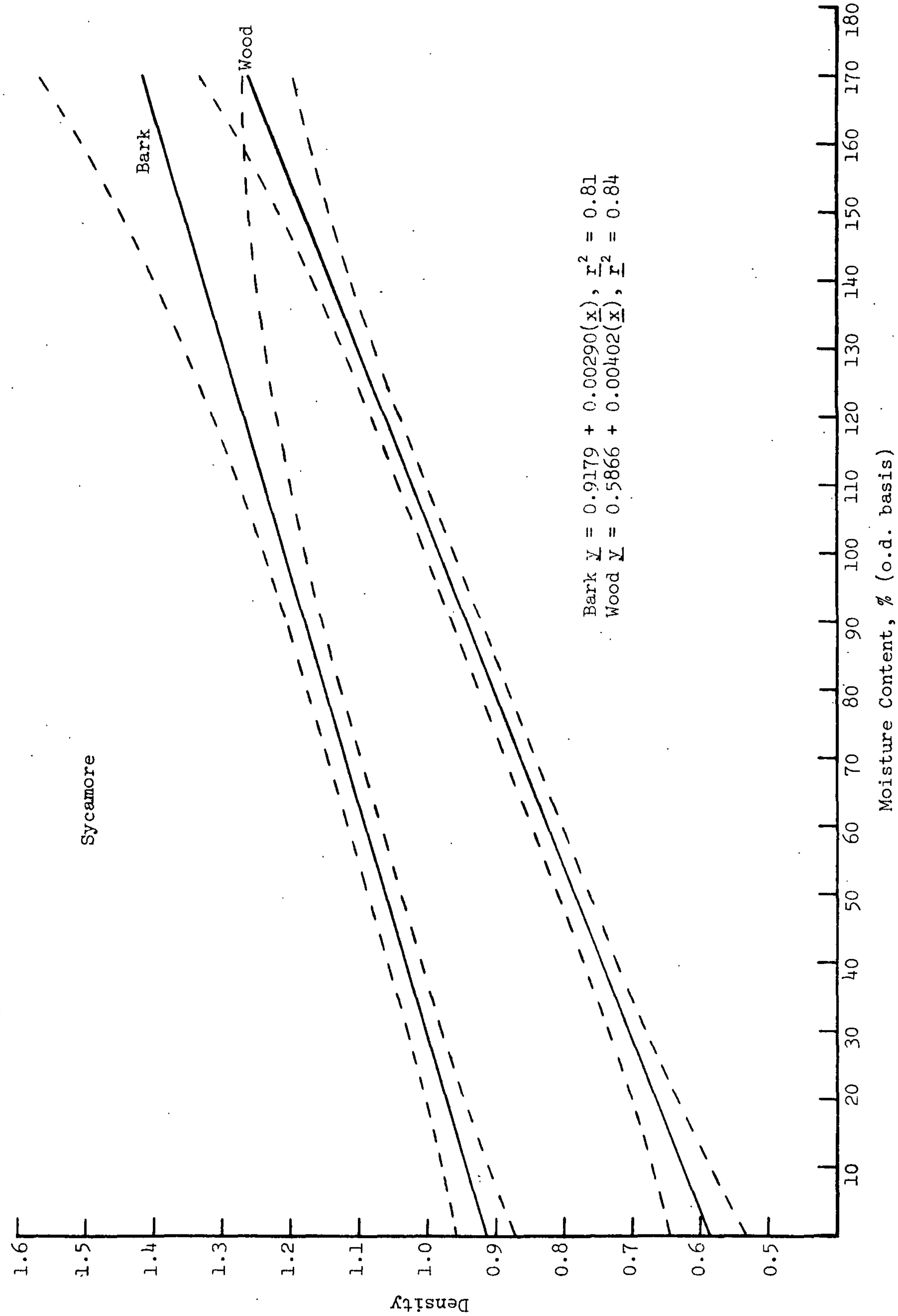


Figure 5. Illustrated is the Relationship Between Basic Density and Moisture Content for Sycamore. The Dashed Lines are Two Standard Deviations Above and Below the Mean

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table VI summarizes the results for sycamore. Some sycamore bark did sink after four hours for both of the trees investigated. Since the chips were placed in the water at 20% moisture content and moisture contents of approximately 30% are needed to effect segregation, the chips that sank probably had picked up enough water to bring them to that moisture content.

DATA INTERPRETATION

Wood/bark adhesion for sycamore is high, indicating some problems could be encountered in separation during the dormant season. However, bark extractives are low and sclereids, which cause "fish eye" problems in paper, are relatively few in number. Sycamore bark is usually thin by nature due to frequent exfoliation and it may be possible in many instances to pulp that part of the bark not removed by a quick screening technique. In fact, when the bark for the two trees investigated in this project was pulped, 98% passed through the 200-mesh screen. This means that very little bark would remain in the pulp even if all the bark was pulped with the wood.

TABLE VI

SUMMARY OF DWELL TIME RESULTS FOR SYCAMORE[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-110	after 5	0	100
Bark	15	0	100
	60	0	100
	240	10.2	89.8
IPC 3212-110	after 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-110	after 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-114	after 5	0	100
Bark	15	0	100
	60	0	100
	240	3.5	96.5
IPC 3212-114	after 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-114	after 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

Segregation of wood/bark chip mixtures through water flotation appears possible at moisture contents between 30 and 90% (o.d. basis). At these moisture contents, bark would sink while the wood would remain floating.

Good reduction of bark levels was obtained through the hammermilling procedure. When the material on the 14-mesh and larger screens was retained, the result was a 7% wood loss and a 45% reduction in levels of bark. Retaining only the material on the 10-mesh and larger screens resulted in an 11% wood loss and 63% bark removal.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (14), Hooper (15) and Biltonen, et al. (16). Several papers deal with short-rotation sycamore including McAlpine, et al. (17) and McAlpine and Brown (18). The chemical composition of fast-growth juvenile wood and slow-growth mature sycamore is discussed in a paper by Moore and Effland (19).

BARK AND WOOD PROPERTIES OF YELLOW POPLAR
(*Liriodendron tulipifera* L.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Yellow poplar is widely distributed throughout the eastern United States, growing from southern New England west to Michigan and south to central Florida and Louisiana. It is most abundant and reaches its greatest size in the Lower Ohio River Basin valley and on the mountain slopes of North Carolina, Tennessee, Kentucky and West Virginia. In this wide range, yellow-poplar is a component of 16 forest cover types and grows under a variety of climatic conditions but develops best where rainfall is distributed over a long growing season. Soil and moisture requirements, moderately moist, well-drained and loose-textured soils, are exacting, with aspect, position on slope and elevation, important factors influencing site quality. Fast growing and unusually free from disease, well-stocked stands on good sites may require thinning at about 20 years to prevent serious retardation in individual tree growth. Thinnings at this time are usually sufficient for pulpwood production. In 50-60 years, good second-growth trees may attain heights of over 120 ft. and diameters of 18-24 inches. Seedlings and saplings are often heavily browsed, and due to the extremely thin bark, are extremely susceptible to fire damage.

WOOD AND BARK MORPHOLOGY

Wood

The sapwood of yellow poplar is whitish in color, often variegated and narrow while the heartwood can be variable in color, ranging from clear yellow to tan or greenish brown. The wood is straight-grained and moderately light and soft. Growth rings are distinct. Vessels are moderately numerous to numerous. The line of marginal parenchyma, delineating growth rings, is 1-several-seriate.

Rays average 4-7 per mm, unstoried or rarely somewhat storied, 1-5 seriate, homocellular to heterocellular. Yellow poplar tracheids are thin to moderately thick-walled, medium to coarse.

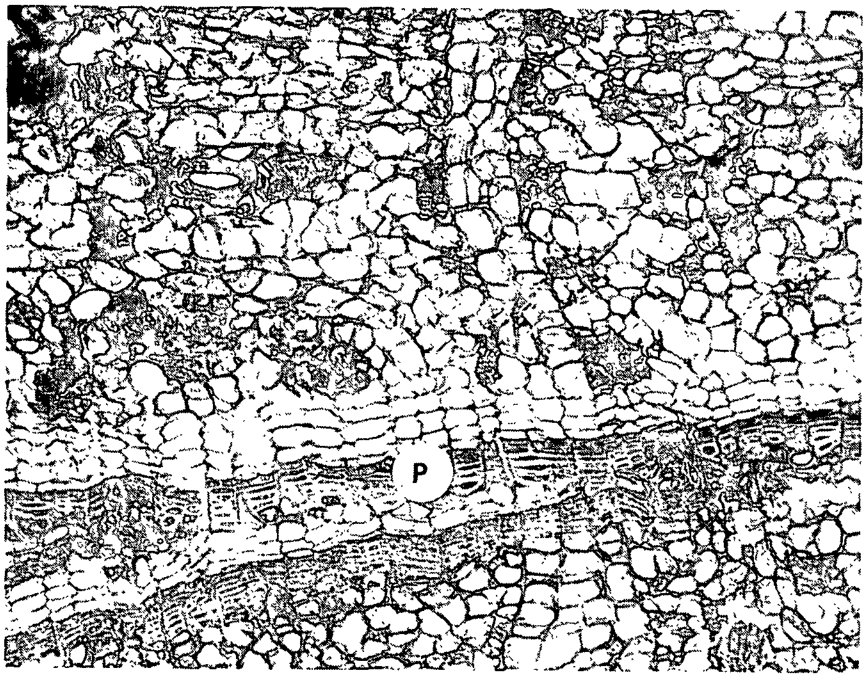
Bark

The bark on young trees is dark green and smooth, with small white spots. The bark soon breaks up into long, rough, interlacing, rounded furrows separated by ashy-gray fissures. The total average thickness on the two trees tested in this project was approximately 12 mm. The average thickness of the inner and outer bark was approximately 5-6 mm and 6-7 mm, respectively. The inner bark averaged 40% by weight. Figure 6 illustrates a cross section of inner and outer bark. Appendix Table XXXI describes the trees used in this study.

Anatomical Structure of Bark

The outer bark or rhytidome of the sample examined was composed of 12-14 layers of periderm and dead secondary phloem tissue. The last-formed periderm was interpreted as having 2-3 layers of phelloderm, a layer of phellogen and several layers of phellem cells. The secondary phloem tissues in the rhytidome were expanded or deformed as compared with those in the inner bark. The peridermal cells and secondary phloem tissue outside the last-formed periderm were mostly lignified.

The inner bark (secondary phloem) was composed of phloem rays and narrow alternate bands of sieve tubes with associated companion cells, phloem parenchyma and sclerenchyma which was confined to phloem fibers. A band of parenchyma cells, 1-2 cells in width, was usually developed above and below the 1-3 tangential layers of sieve tubes. Occasionally, a few parenchyma cells were intermixed with the layers of sieve cells. These cell types were bordered by tangential bands, usually



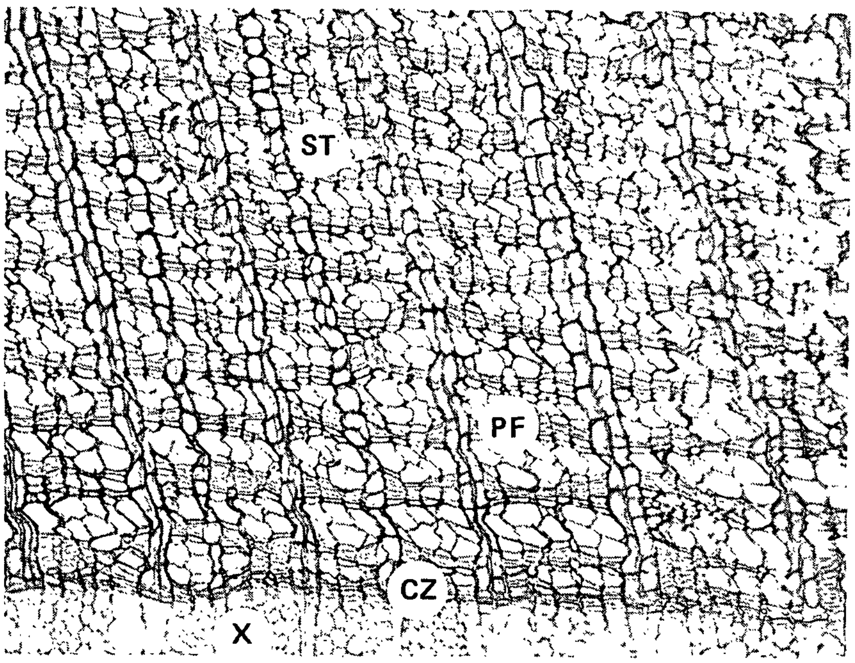


Figure 6. Cross Sections of Yellow Poplar. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Phloem Fibers (PF) and Sieve Tubes (ST). Photograph on Top Shows the Outer Bark with a Periderm Layer (P). Magnification — 75X

numbering 1-3 cells, of phloem fibers which appeared very close to the cambium region (see photomicrographs). The sieve tubes, parenchyma cells and phloem fibers were bordered radially by rays which were mostly 1-3 seriate and essentially homocellular. Some of the rays were conspicuously dilated in the outer region of the inner bark.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures*. Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table VII summarizes the information available on wood and bark of yellow poplar. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of yellow poplar at several moisture contents.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE VII

YELLOW POPLAR SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Av.	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.38				Isenberg (3)
0.40				IUFRO (4)
0.41				Taylor (20)
0.39				Paul and Norton (21)
0.41				Bendtsen and Ethington (22)
0.40			0.36	Schroeder and Phillips (23)
0.41			0.31	Clark, et al. (24)
0.40			0.39	Manwiller (25)
			0.36	Koch (26)
0.39 (sapwood) 0.39 (heartwood)	0.40	0.43	0.43	IPC 3212-102
0.31 (sapwood) 0.35 (heartwood)	0.36	0.42	0.42	IPC 3212-103
0.43[a]				Isenberg (3)
			0.39[a]	Harkin and Rowe (6)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.39 appears appropriate for the wood of yellow poplar. Our samples were divided into heartwood and sapwood and specific gravity determinations made on each. Our limited data show heartwood and sapwood to be close in specific gravity.

The specific gravity of the total (inner + outer) bark of yellow poplar is similar to that of the wood. The outer bark is slightly higher in specific gravity than the inner bark. Overall values suggested for use in species comparisons are 0.39 for wood and 0.38, 0.42 and 0.38 for inner, outer and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

It appears that very little information exists on alcohol-benzene extractives levels of yellow poplar wood and bark. Table VIII summarizes data obtained from the two IPC trees examined. Yellow poplar wood is low in extractives and a level of 3.9% is suggested for use in between-species comparisons. Extractives work done on yellow poplar bark in this project showed an average level of 13.8%. This is a relatively high level compared to other hardwoods examined in this project. However, it should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

TABLE VIII

YELLOW POPLAR ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	4.2	IPC 3212-102
Wood	3.6	IPC 3212-103
Bark	14.4	IPC 3212-102
Bark	13.2	IPC 3212-103

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped yellow poplar bark.

The short, thin-walled sieve tubes that survive the pulping operation could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

Sclereids occur in very minor quantities in yellow poplar bark. They are short, thick-walled, heavily lignified cells and, when not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fish eyes" in certain grades (calendered) of paper. However, the level of sclereids in yellow poplar is so low that they could cause no problem when the bark of this species is being pulped.

As a check on pulp yield and the nature of the material produced from yellow poplar, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table IX summarizes the results of this investigation. Micropulping of yellow poplar bark resulted in a yield of 31.8 to 32.8% solids. When screened, the coarse screens (60- and 100-mesh) retained mostly phloem fibers and a minor amount of sieve tubes. The on 150-mesh screen retained large percentages of phloem fibers and sieve tubes with a small percentage of sclereids. The on 200-mesh and through 200-mesh screens contained mainly sieve tubes and peridermal and parenchymatous cells. Figure 7 illustrates the type of material on the 60- and 150-mesh screens.

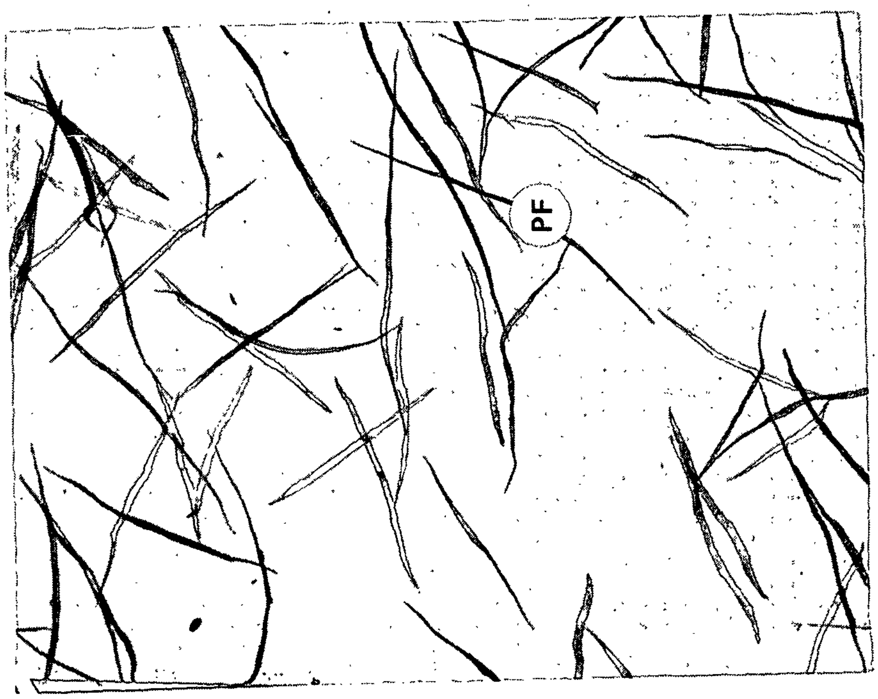
Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, an average of 32.3 grams of solids will result. Of this 32.3 grams, about 13.4 grams (13.4%) of phloem fibers and 1.1 grams (1.1%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

TABLE IX

YELLOW POPLAR MICROPULPING INVESTIGATIONS

Data	Sample No. 3212-102	3212-103	Remarks[a]
Yield, % solids	31.8	32.8	
Fraction			
on 60 mesh, %	41.6	35.9	The fraction contained principally phloem fibers (95+%) with small percentages of sieve tubes (<5%) and peridermal and parenchymatous cells (<5%). The phloem fibers averaged approximately 30 µm in width, 10 µm in thickness and 1.2 mm in length.
on 100 mesh, %	6.6	6.0	The fraction contained a large percentage of phloem fibers (70-80%) with small percentages of sieve tubes (20-30%) and peridermal and parenchymatous cells (<5%) and a trace of sclereids (<1%).
on 150 mesh, %	3.5	4.5	The fraction contained large percentages of phloem fibers (30-40%) and sieve tubes (50-60%) with small percentages of sclereids (5-10%) and peridermal and parenchymatous cells (<5%).
on 200 mesh, %	3.2	3.7	The fraction contained a large percentage of sieve tubes (40-50%) with smaller percentages of peridermal and parenchymatous cells (20-30%), phloem fibers (10-20%) and sclereids (5-10%).
through 200 mesh, %	45.1	49.9	The fraction contained principally peridermal and parenchymatous cells (95+%) with small percentages of phloem fibers (<5%), sieve tubes (<5%) and sclereids (<5%).

[a]Percentages in each fraction on a weight basis.



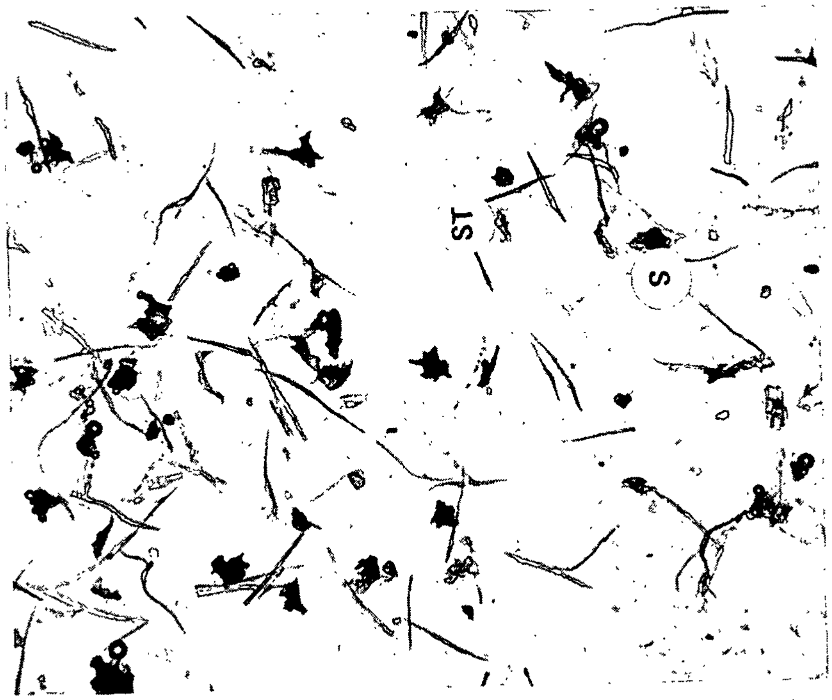


Figure 7. The 60-Mesh Screen (Left) Contained by Weight Principally Phloem Fibers (95+%). The 150-Mesh Screen (Right) Contained Phloem Fibers (30-40%), Sieve Tubes (50-60%) and Sclereids (5-10%). Magnification — 30X. Symbols Illustrate Phloem Fibers (PF), Sieve Tubes (ST) and Sclereids (S)

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for yellow poplar samples collected January 12 (dormant season). Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly formed xylem elements just outside the cambium zone.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 8 illustrates the zone of failure for yellow poplar during the dormant season. Failure occurred in the inner bark, primarily between phloem sieve tubes and parenchyma cells and adjacent tangential bands of phloem fibers close to the cambium zone. Adhesion measurements averaged 16.6 kg/cm^2, a very high value.

As a result of measurement data taken on the species included in Appendix Table XXXII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with yellow poplar. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

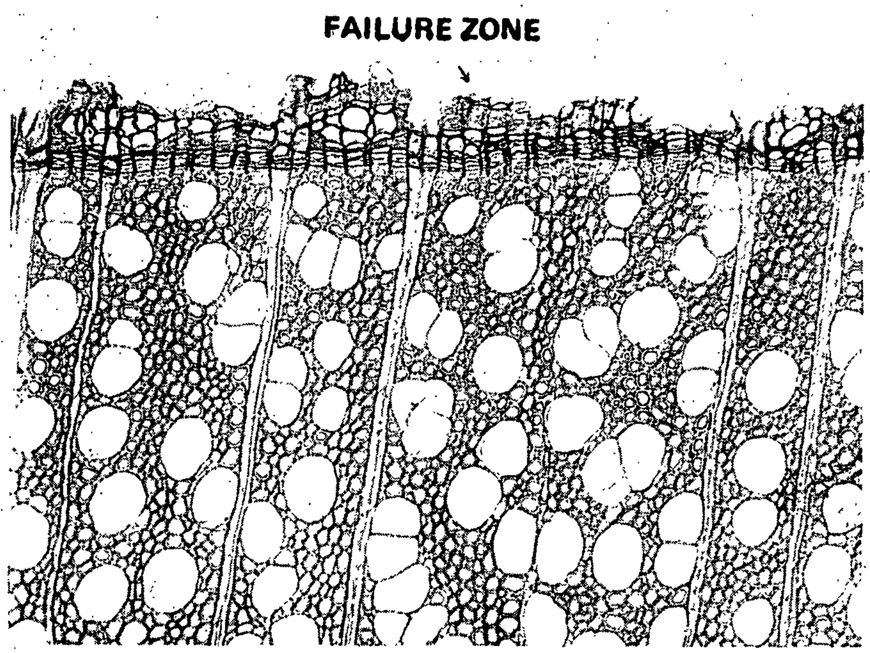


Figure 8. Illustrated is the Yellow Poplar Failure Zone on January 12. Failure Occurred in the Inner Bark, Primarily Between Phloem Sieve Tubes and Parenchyma Cells and Adjacent Tangential Bands of Phloem Fibers Close to the Cambium Zone. Magnification — 75X

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Another method to effect wood/bark separation and segregation that is worthy of consideration is compression debarking. Erickson (27) found bark removal to be good on yellow poplar cut during the dormant season (October) when adhesion is highest. Wood loss amounted to 6.3%. Erickson seemed to feel wood loss could be reduced further with a slight modification of the rolls, i.e., substituting two smooth rolls for the one smooth and one knurled roll used.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table X summarizes the bark strength and toughness tests made on the wood and bark of yellow poplar. Appendix Tables XXXIV and XXXV compare the modulus of elasticity of yellow poplar bark with other species examined in this project.

TABLE X

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF YELLOW POPLAR[a]

Material	Strength	Toughness
Wood	--	0.23
Inner bark	13.4	0.20
Outer bark	10.4	0.18

[a]Determinations average of two different trees.

Bark strength values for yellow poplar inner and outer bark were very high compared to other hardwoods tested thus far. Toughness values for the bark were also high compared to other hardwoods measured but the wood had a relatively low toughness value. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removal by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. This relationship means that yellow poplar should have a low bark removal because of its relatively low specific gravity and high toughness and strength.

Toughness of yellow poplar bark was discussed in a paper by Martin and Crist (28). They found in a toughness test conducted with an FPL intermediate-size toughness tester and tested parallel to the grain that one and a half times as much energy was required to break yellow poplar bark as any of the other species tested, including a number of southern pines, several oaks, American elm, sugar maple and bigtooth aspen. They attributed the high toughness values to fibrous components in yellow poplar bark being immersed in spongelike parenchyma, sieve and periderm cells, which would allow them to yield considerably before rupturing.

Toughness tests on the wood of a number of species, as reported by Wood Handbook (29), were done on both tangential and radial sections and represented the energy required to rapidly cause complete failure in a centrally loaded specimen. Our toughness test is done on a tangential section at 20% moisture content and is a measure of the energy required to rupture a thin specimen by a bending force perpendicular to the grain. Shown in Table XI is a comparison of IPC and Wood Handbook values. Our results are in reasonable agreement with Wood Handbook values.

TABLE XI

COMPARISON OF TOUGHNESS VALUES

Species	I.P.C. Values: Moisture Content, %	I.P.C. Values: Toughness	Wood Handbook Values: Moisture Content, %	Wood Handbook Values: Toughness
Sugar maple	20	1.20	14	360
White oak	20	0.98	13	310
Sweetgum	20	0.28	13	260
Yellow poplar	20	0.23	12	210

Summarized in Table XII are the results of the hammermilling tests run on yellow poplar wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a very modest reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 7% wood loss and a 23% reduction in bark. This is a fairly low bark removal compared to many of the other hardwoods investigated thus far. The low bark removal was expected, however, based upon the toughness and strength tests. A larger amount of bark (30%) could be removed by only retaining the material on the 10-mesh screen and the additional loss in wood would only amount to 2%. Figure 9 illustrates the effect of hammermilling on wood and bark of yellow poplar. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It does not appear that changes in screen design would improve segregation results after hammermilling as the hammermilled bark is stringy and has a shape similar to that of the hammermilled wood. There would not be the differences in configuration of hammermilled wood and bark to use to advantage in screening. Summary Table XXX compares bark strength, toughness and reaction to hammermilling of yellow poplar with other species tested thus far. The section on "Shredding of Chip/Bark Mixtures" compares hammermilling with shredding for both red pine and northern white oak.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are

TABLE XII

SUMMARY OF HAMMERMILLING TEST ON YELLOW POPLAR

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-102	Bark	53.7	17.1	6.7	4.2	6.5	11.8	Large meshes contained mostly inner bark which was stringy in appearance. Fines mostly outer bark.
	Sapwood	82.7	11.5	1.4	0.8	1.3	2.3	
	Heartwood	82.2	9.1	3.0	1.1	1.1	3.5	
3212-103	Bark	53.8	14.7	7.3	3.8	6.0	14.4	Same as for 3212-102.
	Sapwood	75.4	12.7	3.6	2.2	2.0	4.1	
	Heartwood	72.6	16.2	3.9	1.7	1.4	4.2	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

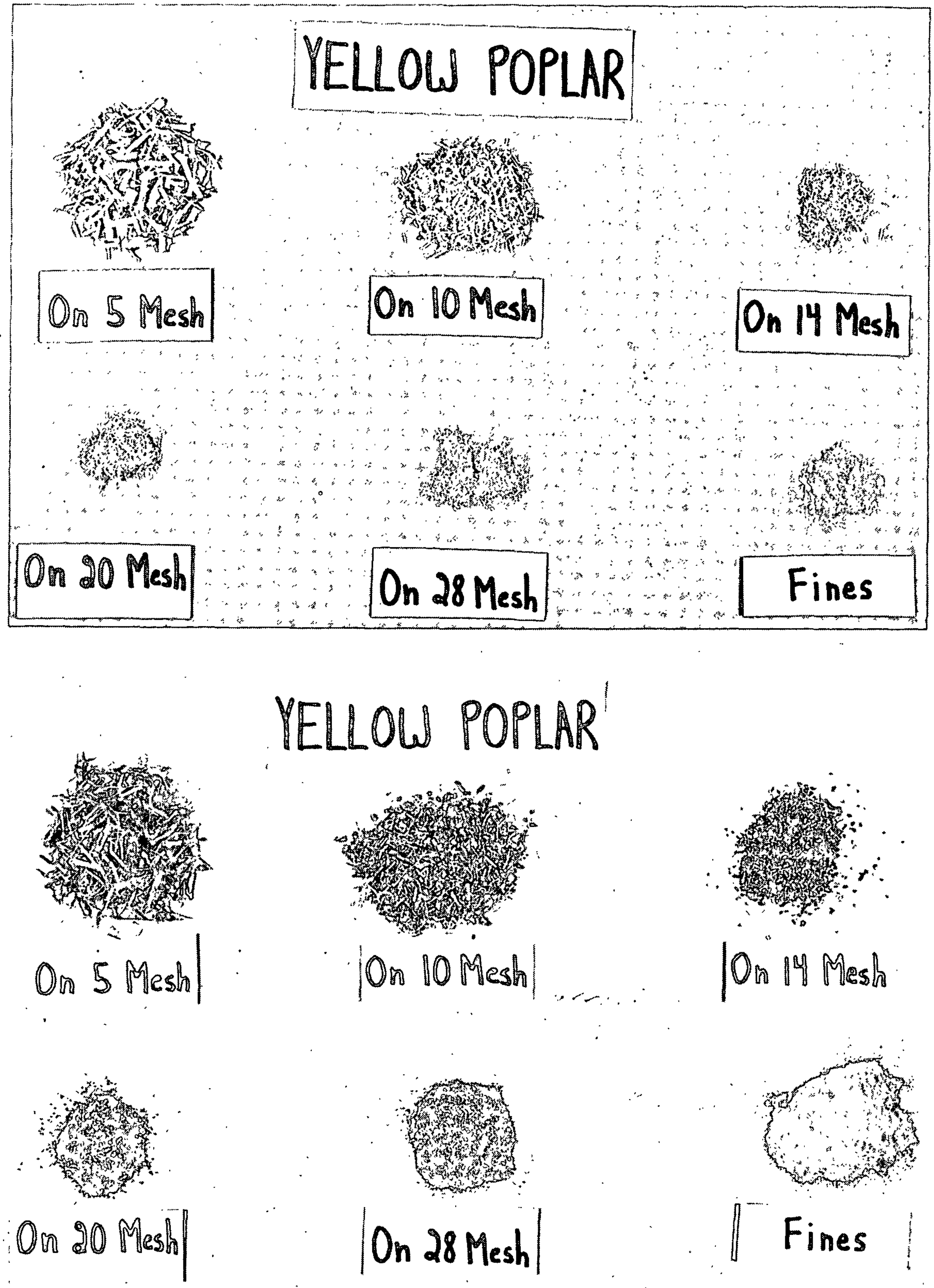


Figure 9. Illustrated is the Effect of Hammermilling on Yellow Poplar Wood (Top) and Bark (Bottom)

employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two yellow poplar trees (IPC 3212-102 and IPC 3212-103) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. Inner, outer and total bark were all very close in density at the various moisture contents.

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

Figure 10 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation is not possible for yellow poplar wood and bark chips through water flotation. Both fractions have densities that are too similar at the various moisture contents and both fractions would float, even at very high moisture contents.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated.

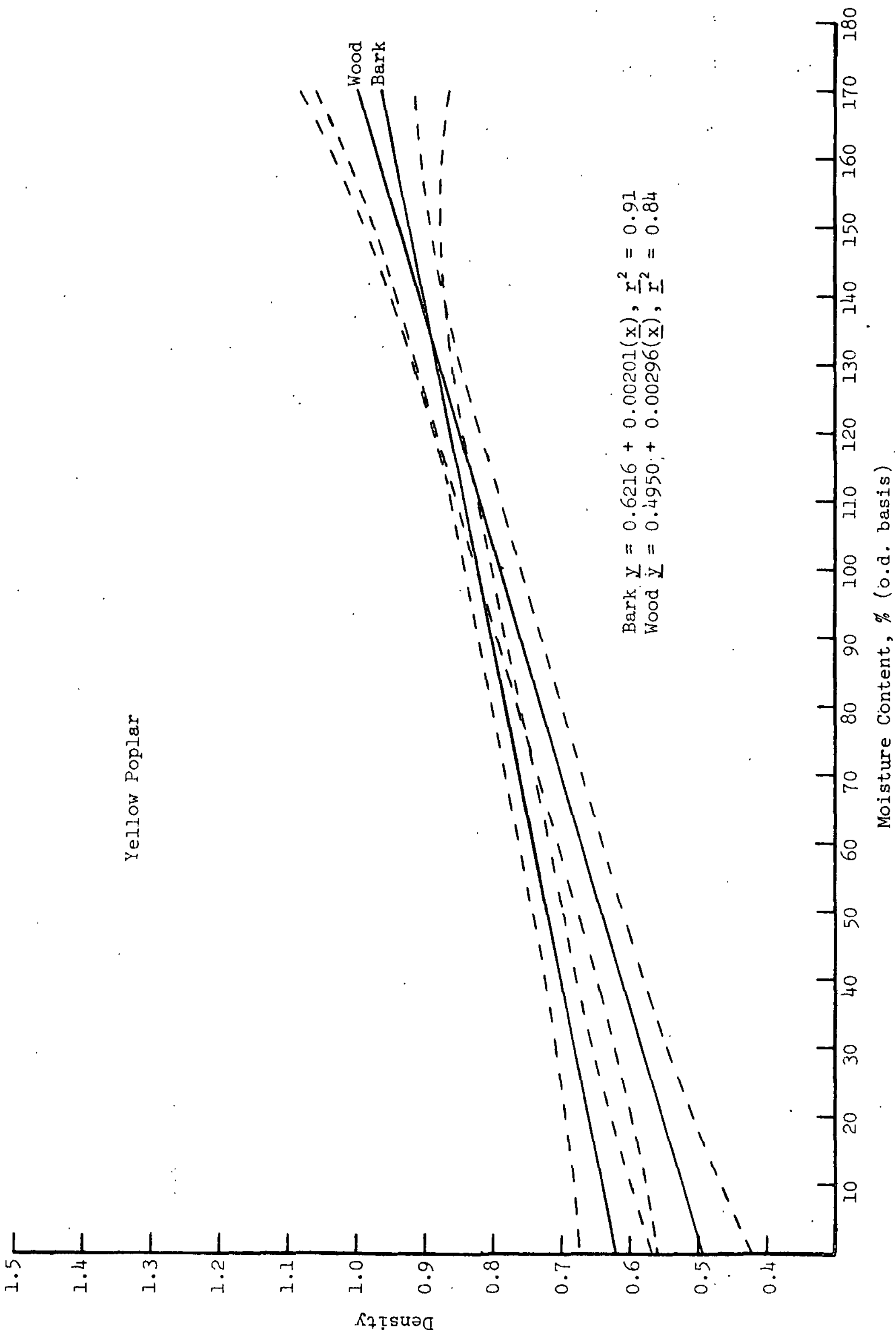


Figure 10. Illustrated is the Relationship Between Basic Density and Moisture Content for Yellow Poplar. The Dashed Lines are Two Standard Deviations Above and Below the Mean

Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XIII summarizes the results for yellow poplar. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content. Detached inner and outer bark would probably behave in a similar manner.

TABLE XIII

SUMMARY OF DWELL TIME RESULTS FOR YELLOW POPLAR[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-102	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-102	after 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-102	after 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-103	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-103	after 5	0	100
Sapwood	15	0	100
	60	0	100
	240	0	100
IPC 3212-103	after 5	0	100
Heartwood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

DATA INTERPRETATION

Since yellow poplar bark is high in extractives, it appears desirable to remove at least part of the bark. Most mechanical treatments remove outer bark which contains no fiber and tend to leave behind a fair amount of inner bark which contains the fiber. Using a treatment like this would reduce the extractives problem while retaining some usable bark fiber. Compression debarking appears to be a mechanical method that would work on yellow poplar. Hammermilling tests gave poor results, a 7% wood loss and only 23% reduction in bark levels when the material on the 14-mesh screen or larger was retained. Retaining only the material on the 10-mesh or larger screens resulted in a 9% wood loss and 30% reduction in bark levels. No segregation was possible through water flotation with wood and bark having similar densities at the same moisture content.

Pulping yellow poplar bark resulted in 13.4 grams of phloem fibers and 1.1 grams of sieve tubes produced for every 100 grams of bark that is pulped. Perhaps, for many products, the best approach would be screening to concentrate the bark in a particular size fraction (smaller chips), treating that fraction by compression debarking or a similar technique and pulping the remaining small amount of bark in view of the fiber it contains.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (14), Hooper (15) and Biltonen, *et al.* (16). Bark volume of yellow poplar is covered in a paper by Koch (30).

BARK AND WOOD PROPERTIES OF BLACK TUPELO
(*Nyssa sylvatica* Marsh.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

Black tupelo and swamp tupelo (*Nyssa aquatica* L.), an associated species, grow throughout most of the eastern United States. Black tupelo grows in the uplands and in alluvial stream bottoms throughout most of the eastern United States from southwestern Maine to eastern Texas. Swamp or water tupelo develops best in the coves and low swamps and is limited to the Coastal Plain swamps and estuaries of the southeast. Both ranges are in the humid zone with similar climatic characteristics. However, black tupelo, in the larger range, grows in colder, drier climates than swamp tupelo and on well-drained light-textured soils and loams and adapts readily to a variety of sites. Tolerant of wetter sites, swamp tupelo is found on wet bottom land soils ranging from highly organic muck to heavy clays in ponds and sloughs. Both varieties reach a mature height of 120 ft. with diameters at breast height often exceeding 4 ft. on favorable sites. Diameter growth averages 4-5 inches for 10 years on medium sites. Characterized in this report is *Nyssa sylvatica* Marsh.

WOOD AND BARK MORPHOLOGY

Wood

Black tupelo sapwood is white to grayish white merging gradually into the darker, greenish or brownish gray heartwood. The wood is moderately hard and moderately heavy usually with interlocked grain. Growth rings are indistinct. Pores, not visible to the naked eye, are small, numerous and fairly evenly distributed. Rays are fine, indistinct on cross section and very close, appearing to form one-half the wood surface.

Black tupelo xylem consists of numerous vessels, traces of longitudinal parenchyma, fiber tracheids and rays. Vessels, occupying 38.4% of the total wood volume, average 80 to 180 per sq. mm. The largest vessels are 60-90 µm in diameter and average 1.33 mm with a standard deviation of 0.34 in length. Spiral thickening, restricted to the tapering end of the vessel, is occasionally present. The perforation plates are exclusively scalariform with numerous small bars. Parenchyma are scattered as paratracheal and metatracheal-diffuse. The fibers, moderately thick to thick-walled, average 2.30 mm in length with a standard deviation of 0.36 and account for about 45% of the wood volume. Rays, 8-13 per mm on cross section, are unstoried, 1-4 seriate and heterogeneous with the upright cells restricted generally to the upper or lower margins. Occupying 16.6% of the wood volume, rays measure less than 60 µm in height.

Bark

Bark of the young black tupelo is gray with shallow fissures and flaky scales. Old trunks are grayish brown and deeply furrowed, similar in pattern to alligator hide. Rhytidome layers form broad, flat ridges that are often checked horizontally. The light brown inner bark, on cross section, shows discontinuous broad bands of sclerenchyma aligned tangentially and often above or closely connected to fine bands. In the outer bark, the sclerenchyma bands are fewer in number but distinct to the naked eye as are the brownish-yellow peridermal lines. The inner bark of the trees characterized averaged 40% by weight. Figure 11 illustrates a cross section of inner and outer bark. Appendix Table XXXI describes the trees used in this study.

Anatomical Structure of Bark

In young bark the periderm consists of suberized phellem cells and a layer each of phellogen and phelloderm. The cortex is composed of a few layers of

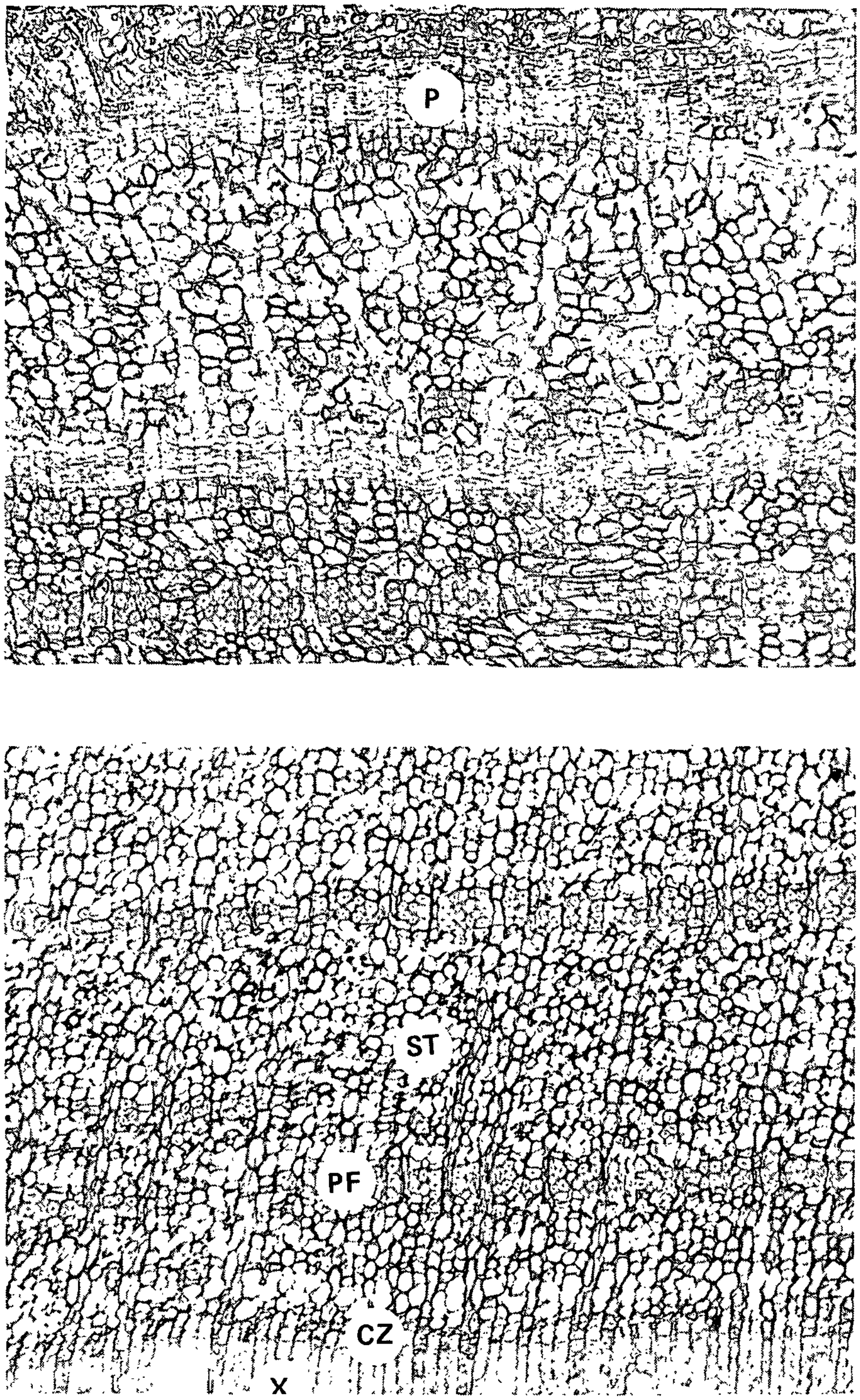


Figure 11. Cross Sections of Black Tupelo. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Phloem Fibers (PF) and Sieve Tubes (ST). Photograph on Top Shows Periderm Layers (P) of Outer Bark. Magnification — 75X

collenchyma and ordinary parenchymatous cortex cells often containing crystals, which are probably calcium oxalate. Primary phloem fibers are in isolated groups with sclereids distributed among them and forming connected bands encircling the phloem. Parenchymatous cells and sieve tubes form most of the secondary phloem in the young bark.

Periderm in the mature bark usually consists of a broad band of phellem, a layer of phellogen and 1 or 2 layers of poorly developed phelloderm. There are usually 5 layers of thick-walled, conspicuously suberized phellem cells close to the phellogen followed by 5 or more layers of larger, thinner-walled, first-formed phellem. The phelloderm and phellogen cells, much narrower than the phellem, often become "lignified." Periderm formation is frequent. For each rhytidome layer, there is only one band of sclerenchyma.

The secondary phloem of black tupelo is composed of sieve tubes and sporadic parenchyma confined by phloem rays and sclerenchyma on cross section. The sieve tubes, usually 30-50 μm in diameter, are solitary or in short radial multiples. Sieve tube elements vary from 520-1205 μm in length with companion cells at the narrow dimension. Sporadic or in reticulate formation, parenchyma, in 1-3 layers appear adjacent to the fiber bands on the cambium side and may initiate new periderm. Cells often contain tanniferous substances and crystals and may become sclerified and form sclereid groups with other cells. Sclereids and typical phloem fibers form the sclerenchyma. Sclereids of transformed parenchyma strands and phloem ray cells are thick-walled and not much branched, often containing solitary crystals, probably composed of calcium oxalate. A sclereid group is often 10 or more cells wide on radial dimension and always closely connected with a fiber band. Fibers, developing earlier than the sclereids, are aligned in generally tangentially narrow bands of 3-4 layers. On cross section, they are polygonal in shape, about

25 µm in diameter and have very thick walls and narrow lumina. With pointed ends, the fibers vary in length from 0.72 to 2.33 mm. According to Chang, the mean length is 1.47 mm with the standard deviation of 0.39. Phloem rays are heterogeneous and both uniseriate and multiseriate with high marginal cells. The uniseriate rays, usually 6-10 cells high but up to 20+, are composed of generally square and upright cells. Multiseriate rays, 2, 3 and sometimes 4-seriate, often vertically fuse and form a very high ray of mainly upright cells. Rays are spaced quite closely and do not dilate much at the outer margin of the inner bark.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XIV summarizes the information available on wood and bark of black tupelo. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that several of the values in the table are ovendry weights divided by ovendry volumes. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

basic density (green weight divided by green volume) of black tupelo at several moisture contents.

TABLE XIV

BLACK TUPELO SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Av.	Bark Inner	Bark Outer	Bark Total	References and Remarks
0.46				Bendtsen and Ethington (22)
0.46				Isenberg (3)
0.46				IUFRO (4)
0.50			0.43	Manwiller (25)
			0.51	Choong and Cassens (31)
0.54 (exterior) 0.52 (interior)	0.41	0.32	0.38	IPC 3212-111
0.54 (exterior) 0.50 (interior)	0.34	0.42	0.42	IPC 3212-115
			0.55[a]	Harkin and Rowe (6)
0.54[a]				Isenberg (3)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.49 appears appropriate for the wood of black tupelo. Our samples were divided into interior and exterior wood and specific gravity determinations made on each. For 3212-111, the interior wood constituted the first 8 rings out of a total 28 rings and the first 16 rings out of a total 36 rings for 3212-115. Our limited data show the interior and exterior wood to be close in specific gravity.

The specific gravity of the total (inner + outer) bark of black tupelo is slightly lower than that of the wood. No definite trends could be established for inner and outer bark specific gravity on the samples we examined. The outer bark was lower in specific gravity than the inner bark for 3212-111 and the reverse was true for 3212-115. Overall values suggested for use in species comparisons are 0.49 for wood and 0.44 for total bark. Because other literature values were used in obtaining the total bark specific gravity, the average turned out higher than the averages for inner and outer bark in the table. Inner and outer bark specific gravity from the two trees measured in this project averaged 0.38 and 0.37, respectively.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Some information exists on alcohol-benzene extractives levels of both black tupelo wood and bark. Table XV summarizes existing data and includes the two IPC trees examined. Black tupelo wood is low in extractives and a level of 3.1% is suggested for use in between-species comparisons. Extractives work done on black tupelo bark in this project plus two additional values showed an average level of 8.9%. This is a relatively low level and indications are that extractives are not expected to be a serious problem when pulping the bark of this species.

TABLE XV

BLACK TUPELO ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	3.4	Isenberg (3)
Wood	3.0	IPC 3212-111
Wood	3.0	IPC 3212-115
Bark	7.1	Harkin and Rowe (6)
Bark	7.1	Chang and Mitchell (32)
Bark	10.6	IPC 3212-111
Bark	10.7	IPC 3212-115

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped black tupelo bark.

The short, thin-walled sieve tubes that survive the pulping operation could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

Sclereids occur in very minor quantities in black tupelo bark. They are short, thick-walled, heavily lignified cells and, when not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fish eyes" in certain grades (calendered) of paper. Chang (1) estimated that sclereids made up 19.3% of the tissue elements in the secondary phloem of black tupelo. However, almost all of these are lost in the pulping operation and sclereids should cause no problems when the bark of black tupelo is being pulped.

As a check on pulp yield and the nature of the material produced from black tupelo, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micro-pulping Procedure. Table XVI summarizes the results of this investigation. Micro-Pulping of black tupelo bark resulted in a yield of 29.6 to 33.3% solids. When screened, the coarse screens (60- and 100-mesh) retained mostly phloem fibers and a minor percentage of sieve tubes. The on 150-mesh screen retained a large percentage of phloem fibers plus some sieve tubes and peridermal and parenchymatous cells. The on 200-mesh screen and through 200-mesh screens contained large percentages of peridermal and parenchymatous cells, some sieve tubes and small percentages of other elements. Figure 12 illustrates the type of material on the 60- and 150-mesh screens.

TABLE XVI

BLACK TUPELO MICROPULPING INVESTIGATIONS

Data	Sample No. 3212-111	Sample No. 3212-115	Remarks[a]
Yield, % solids	33.3	29.6	
Fraction			
on 60 mesh, %	2.7	31.0	The fraction of the tree examined (3212-115) contained 100% phloem fibers. Average arithmetic fiber length was 1.25 mm.
on 100 mesh, %	2.0	2.2	The fraction contained principally phloem fibers (95+%) with a small percentage of sieve tubes (<5%) and a trace of parenchymatous cells (<1%).
on 150 mesh, %	4.3	1.0	The fraction contained phloem fibers (50-60%), sieve tubes (20-30%), peridermal and parenchymatous cells (10-20%) and sclereids (<5%).
on 200 mesh, %	4.6	1.5	The fraction contained large percentages of peridermal and parenchymatous cells (60-70%), sieve tubes (30-40%), with small percentages of phloem fibers (5-10%) and sclereids (<5%).
through 200 mesh, %	86.4	64.3	The fraction contained principally peridermal and parenchymatous cells (80-90%) with small percentages of crystalliferous parenchyma (5-10%), sieve tubes (<5%) and a trace of sclereids (<1%).

[a]Percentages in each fraction on a weight basis.

The two black tupelo trees examined exhibited big differences in the amount of material retained on the 60-mesh screen. The pulping and classification procedure was rerun, using new samples from each tree and results were essentially the same. When the classified material from the first run was examined, the fractions from Tree 3212-111 were found to be contaminated with wood. However, it does not appear

Figure 12. The 60-Mesh Screen (Left) Contained by Weight 100% Phloem Fibers. The 150-Mesh Screen (Right) Contained Phloem Fibers (50-60%), Sieve Tubes (20-30%), Peridermal and Parenchymatous Cells (10-20%) and Sclereids (<5%). Magnification — 30X. Symbols Illustrate Phloem Fibers (PF), Sieve Tubes (ST)

that the wood contamination significantly influenced the amount of material that fell on each screen since the rerun results were so similar.

The differences obtained between the two trees are difficult to explain. Relative percentages of inner and outer bark were the same for both trees but Tree 3212-115 had a greater total percentage of bark (10.2%) than did Tree 3212-111 (7.6%) and, therefore, more inner bark. Since the inner bark contains fiber, more material could end up on the 60-mesh screen.

Amounts of the different elements were calculated using the percentages obtained from Tree 3212-115. Based upon this very limited bark sample observation, it appears that, for every 100 grams of bark that is pulped, an average of 31.4 grams of solids will result. Of this 31.4 grams, about 10.5 grams (10.5%) of phloem fibers will be produced. However, the percent phloem fibers retained on the 60- and 100-mesh screens was much less for 3212-111, only 1.4%. For both trees, this assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for black tupelo samples collected March 1 (dormant season). Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly formed xylem elements just outside the cambium zone.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 13 illustrates the zone of failure for black tupelo during the dormant season. Failure occurred in the inner bark between sieve tubes and phloem parenchyma cells in the proximity (0.1-0.2 mm) of the cambium zone. Adhesion measurements averaged 13.5 kg/cm^2, a high value.

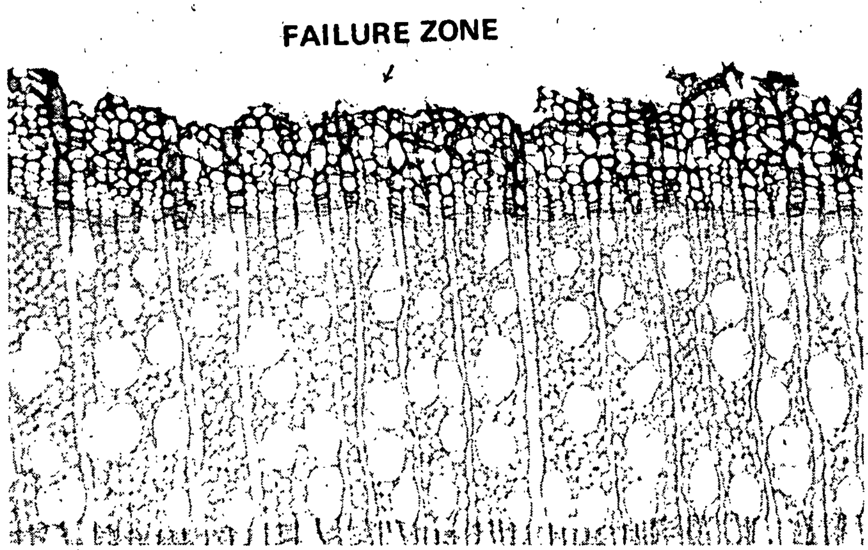


Figure 13. Illustrated is the Black Tupelo Failure Zone on March 1. Failure Occurred in the Inner Bark Between Sieve Tubes and Phloem Parenchyma in the Proximity of the Cambium Zone. Magnification — 75X

As a result of measurement data taken on the species included in Appendix Table XXXII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with black tupelo. High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Another method to effect wood/bark separation and segregation that is worthy of consideration is compression debarking. Erickson (27) found bark removal to be good for black tupelo cut during the dormant season (October) when adhesion is highest. Wood loss ranged from 0.9 to 3.4%.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measured shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XVII summarizes the bark strength and toughness tests made on the wood and bark of black tupelo. Appendix Tables XXXIV and XXXV compare the modulus of elasticity of black tupelo bark with other species examined in this project.

TABLE XVII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF BLACK TUPELO[a]

Material	Strength	Toughness
Wood	--	0.56
Inner bark	9.6	0.20
Outer bark	10.5	--[b]

[a]Determinations average of two different trees except outer bark strength which is based on 3212-115.
[b]Unable to be tested due to numerous small cracks.

Bark strength values for black tupelo inner and outer bark were high for tree #115 and moderate for tree #111 compared to other hardwoods tested thus far. Toughness values for inner bark were also relatively high for tree #115 and very low for tree #111. No toughness tests could be performed on outer bark because of numerous small cracks. Toughness values for the wood were lower than any hardwood tested thus far. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removal by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Bark specific gravity values for black tupelo were somehwat low compared to other hardwoods tested thus far. This, combined with moderately high bark strength and toughness, would indicate that hammermilling or other mechanical separation and segregation techniques would work fairly well for tree #111 and not nearly as well for tree #115.

Summarized in Table XVIII are the results of the hammermilling tests run on black tupelo wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in a fairly good reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 5% wood loss for both trees but a big difference in the amount of bark removed. As predicted by the toughness and strength tests, bark removal was good (54%) for 3212-111 and not nearly as good for 3212-115 (23%). A larger amount of bark could be removed for both trees by only retaining the material on the 10-mesh screen without a much greater loss of wood. For 3212-111 this amounted to a 70% bark removal and 7% wood loss and 31% bark removal and 9% wood loss for 3212-115. Figures 14 and 15 illustrate the effect of hammermilling on wood and bark of black tupelo. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It does not appear that changes in screen design would improve segregation results after hammermilling for 3212-115 as the hammermilled bark was stringy and had a

TABLE XVIII

SUMMARY OF HAMMERMILLING TEST ON BLACK TUPELO

Tree No.	Material	Fraction Retained on Standard Screen[a], % 5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	Remarks
3212-111	Bark	9.4	20.7	15.5	10.0	18.1	26.3	Bark not stringy like 3212-115 but rather more rounded pieces. All meshes contained a combination of inner and outer bark.
	Exterior wood	79.6	14.8	1.4	0.7	0.8	2.7	
	Interior wood	79.8	12.5	2.9	1.4	1.0	2.4	
3212-115	Bark	49.4	19.3	8.2	4.6	3.8	14.7	Large mesh screens contained mostly inner bark which was stringy in appearance. Fines mostly outer bark.
	Exterior wood	82.7	10.1	2.9	1.3	1.1	1.9	
	Interior wood	71.2	18.4	4.8	2.0	1.6	2.0	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

shape similar to that of the hammermilled wood. There would not be the differences in configuration to use to advantage in screening. However, for 3212-111, the bark had a different shape than the wood and it is possible improvements could be made in screening results by taking advantage of the differences in configuration evident in Fig. 15 (12,13). This would require changes in screen design. The differences exhibited by these two black tupelo trees in hammermilling, bark strength, toughness and pulping results are greater than usually encountered between two trees of the same species in this project. However, it again points up the variation among trees of the same species and the need to look at the results with this in mind. Summary Table XXX compares bark strength, toughness and reaction to hammermilling of black tupelo with other species tested thus far. The section on "Shredding of Chip/Bark Mixtures" compares hammermilling with shredding for both red pine and northern white oak.

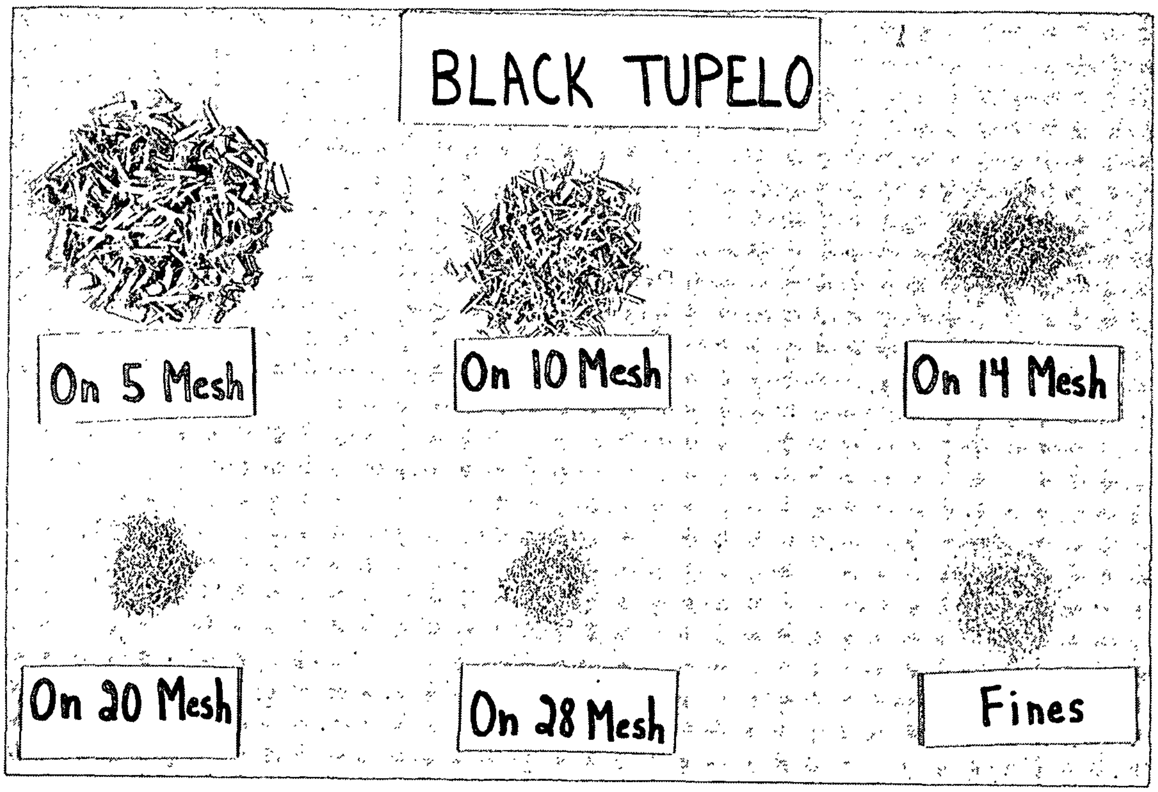
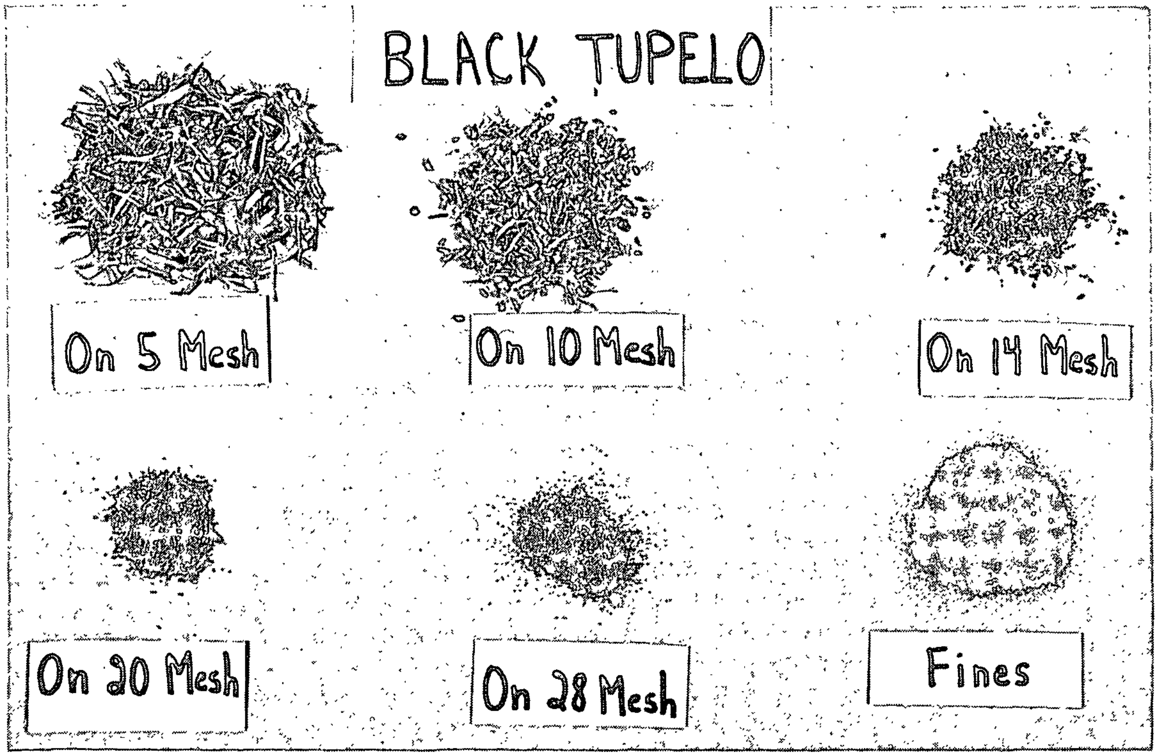


Figure 14. Illustrated is the Effect of Hammermilling on Black Tupelo Wood



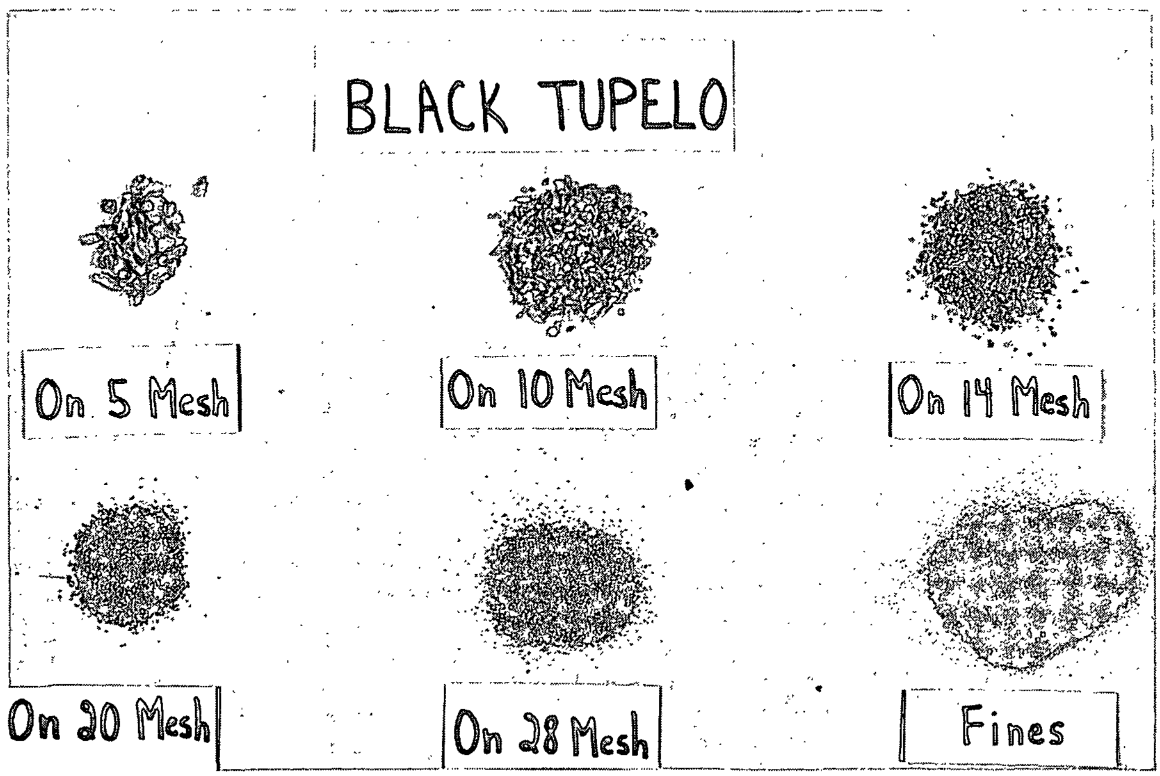


Figure 15. Illustrated is the Effect of Hammermilling on the Bark of Black Tupelo Tree 3212-115 (Top) and 3212-111 (Bottom). Differences in the Appearance of the Bark After Hammermilling are Evident

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two black tupelo trees (IPC 3212-111 and IPC 3212-115) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

of both inner and outer bark. Small chips of inner and outer bark were also tested. Outer bark had a slightly lower density at the various moisture contents than did whole bark. Only a very limited number of inner bark samples were tested because, after the bark had air-dried, the inner bark became brittle and difficult to separate from the outer bark. The samples tested indicated inner bark has a slightly higher density than whole bark at various moisture contents.

Figure 16 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that segregation is not possible for black tupelo wood and bark chips through water flotation. Both fractions have densities that are too similar at the various moisture contents.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and

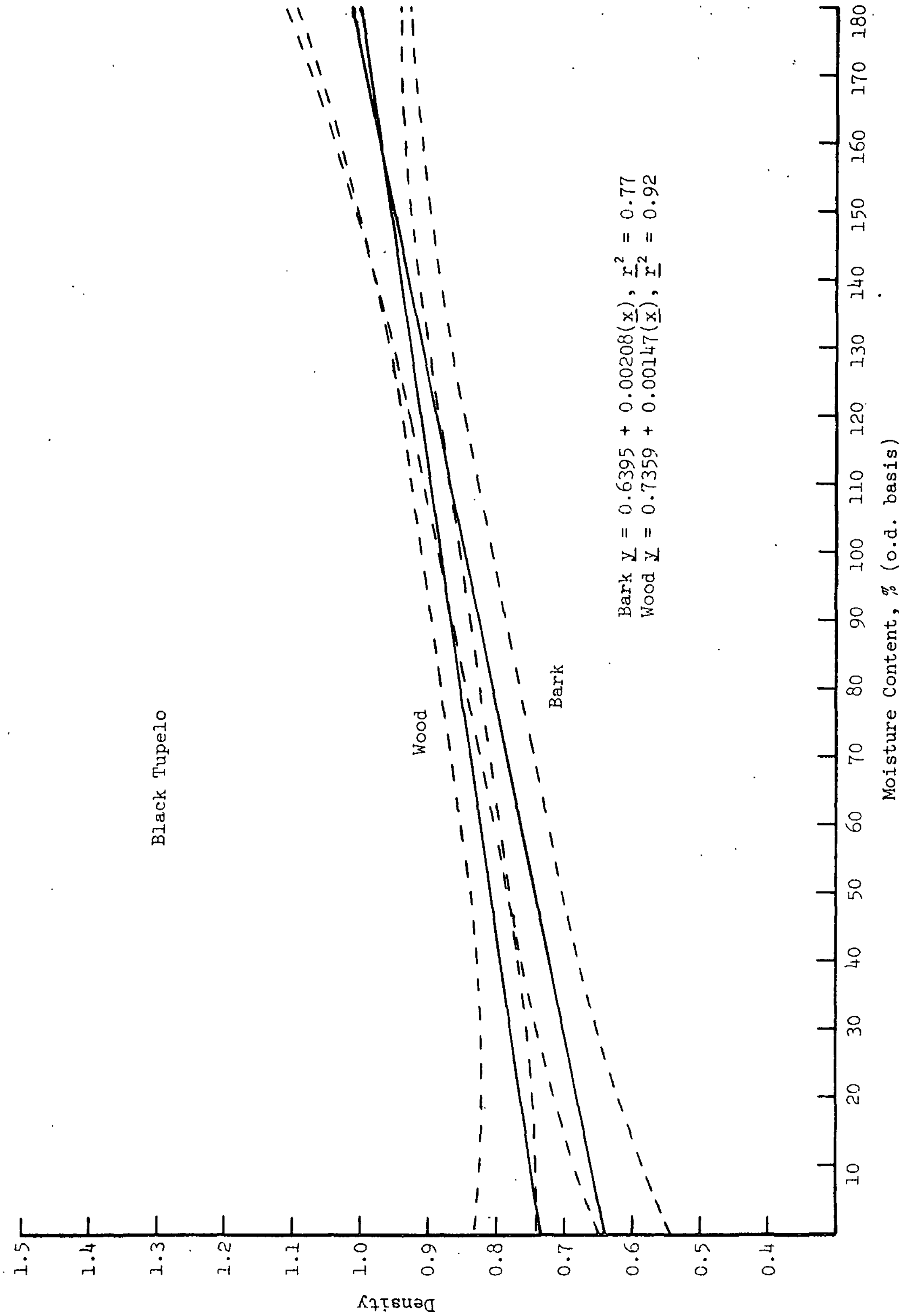


Figure 16. Illustrated is the Relationship Between Basic Density and Moisture Content for Black Tupelo. The Dashed Lines are Two Standard Deviations Above and Below the Mean

would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XIX summarizes the results for black tupelo. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content.

DATA INTERPRETATION

The two black tupelo trees examined in this project reacted very differently to the hammermilling tests and the classification after pulping. However, they were from widely separated geographic locations (North Carolina and Arkansas). The differences obtained between these two trees point up the variation within species and the need to regard the data presented in these reports as general trends.

Black tupelo bark is low in extractives and contains very little in the way of sclereids which can cause "fish eyes" in paper. In addition, it contains usable fiber. All of these characteristics make the pulping of black tupelo bark a possibility in certain instances. For every 100 grams of bark that is pulped, between 1.4 and 10.5 grams of fiber will be produced.

It appears that compression debarking would work on this species if at least part of the bark needed to be removed. Our hammermilling results were variable, with bark removal ranging from 23 to 54%. (The results were, however, as expected based upon bark strength and toughness.) In addition, the shape of the simulated chips of the two trees after hammermilling was quite different with one stringy and the other having more rounded pieces. More work would need to be done on hammermilling with this species to determine its effectiveness.

TABLE XIX

SUMMARY OF DWELL TIME RESULTS FOR BLACK TUPELO[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-111	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-111	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-111	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-115	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-115	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-115	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

Segregation through water flotation would not work with this species. Both wood and bark have densities that are too similar at various moisture contents.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (14), Hooper (15) and Biltonen, *et al*. (16). Wood and bark moisture contents of black tupelo and several other hardwoods are discussed in a paper by Manwiller (33).

BARK AND WOOD PROPERTIES OF WHITE ASH
(*Fraxinus americana* L.)

SILVICULTURAL CHARACTERISTICS AND GEOGRAPHIC RANGE

White ash, the largest and commonest (but not the most widespread) of the American ashes, has a natural range covering most of the eastern half of the United States from Nova Scotia west to eastern Minnesota and south to eastern Texas and northern Florida. Within this wide range, white ash grows under highly variable climatic factors, and elevations range from near sea level to about 3500 ft. in the Cumberland Mountains. Local distribution is limited by the species demanding requirements in regard to soil moisture and fertility. White ash reaches its best development on moderately well-drained soils and grows most commonly on fertile soils with a high nitrogen content and moderate to high calcium content with pH tolerance from 5.0-7.5. In mature forests, heights of 70-80 ft. are common and some trees in the Ohio River bottom lands attain heights of 120 ft. and 6 ft. dbh. White ash is easily propagated by conventional methods of budding and grafting, and sprouts readily from freshly cut stumps of seedlings and saplings. Young ash trees have a strong apical dominance that causes them to grow vertically and comparatively branch free and open-grown trees commonly remain single stemmed with only fine branches until they are 30-40 years old.

WOOD AND BARK MORPHOLOGY

Wood

White ash has a nearly white sapwood and a heartwood that is grayish brown, light brown or pale yellow streaked with brown. The wood is straight-grained, heavy and hard with distinct growth rings (ring porous). Earlywood pores are large, distinctly visible to the naked eye while latewood pores are small and barely visible. Parenchyma are visible with a hand lens, paratracheal-vasicentric, paratracheal-aliform to confluent in the outer latewood and marginal. Rays are not distinct or barely visible to the naked eye, unstoried, 1-3 seriate and homocellular. Vasicentric tracheids are present, confined to the immediate vicinity of the earlywood vessels. Libriform fibers are thin-to-medium thick-walled, fine-to-medium.

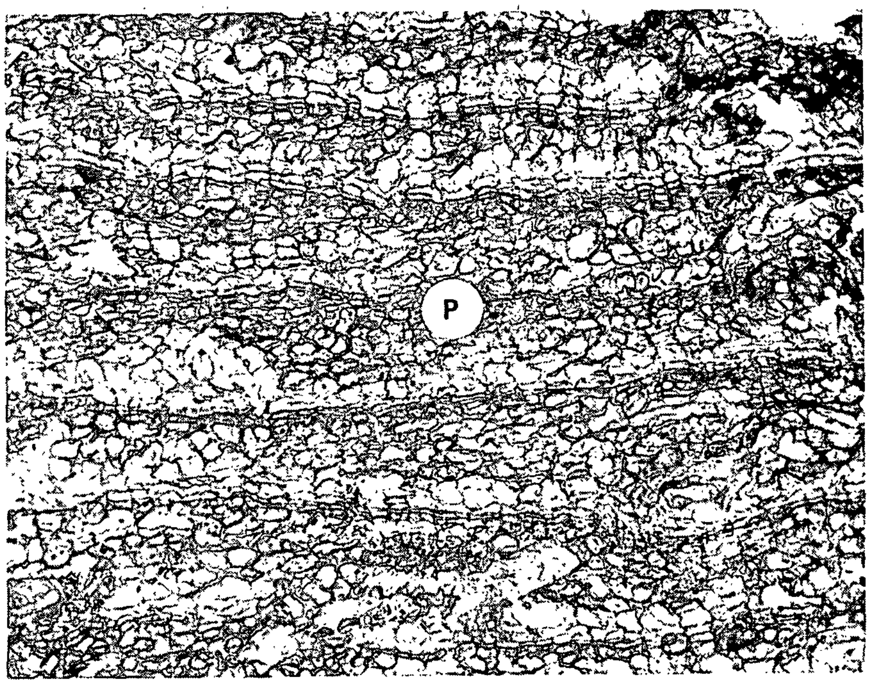
Bark

The bark of white ash is ashy gray or the young stems may have an orange tinge. Later the bark becomes finely furrowed into close diamond-shaped areas separated by narrow interlacing ridges. On very old trees the bark is slightly scaly along the ridges. The total thickness of the bark on the two trees tested for this project averaged approximately 12-14 mm. The average thickness of the inner and outer bark was approximately 4-5 mm and 8-9 mm, respectively. The inner bark averaged 45% by weight. Figure 17 illustrates a cross section of inner and outer bark. Appendix Table XXXI describes the trees used in this study.

Anatomical Structure of Bark

The outer bark or rhytidome consists of many regularly spaced layers of periderm and dead secondary phloem tissue. A periderm is composed of 2-3 layers of phelloderm, a layer of phellogen and several, usually 3-5, layers of thin-walled phellem cells. The walls of most cells in the outer bark are lignified.

The secondary phloem is composed of phloem rays, alternate bands of sieve tubes, phloem parenchyma and sclerenchyma which is restricted to phloem fibers. The general arrangement is (a) sieve tubes, 1-2 cells in width, alternating with (b) phloem parenchyma, 1-2 cells in width, bordered by (c) discontinuous tangential layers or bands of thick-walled phloem fibers varying from 2-8 cells in width. The sieve tubes and phloem parenchyma retain, more or less, their original shape and size throughout most of the inner bark after they become functionless.



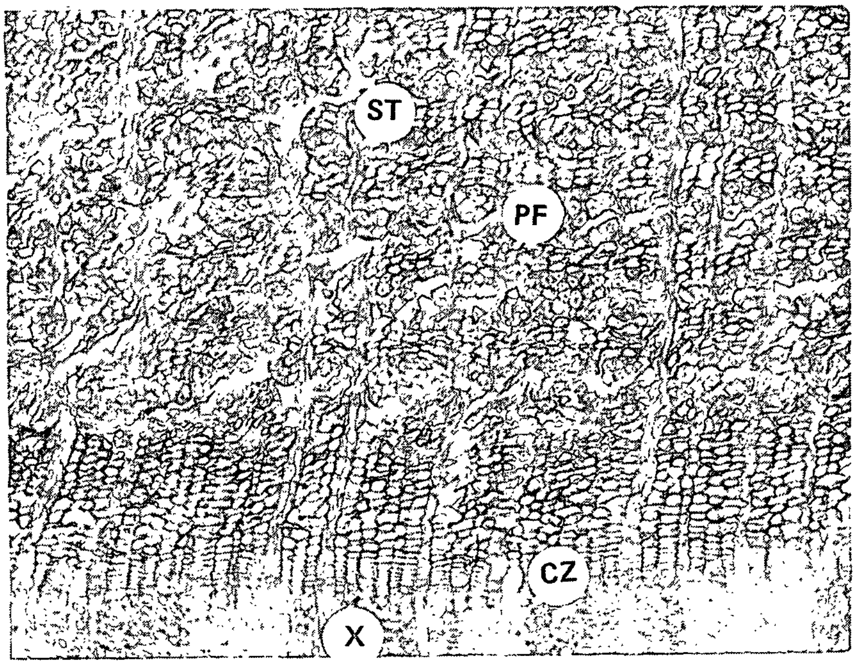


Figure 17. Cross Sections of White Ash. Photograph on Bottom Shows Xylem (X), Cambium Zone (CZ), Phloem Fibers (PF) and Sieve Tubes (ST). Photograph on Top Shows Periderm Layers (P) of the Outer Bark. Magnification — 75X

The phloem fibers are more or less round in cross section, averaging approximately 20-25 µm in diameter. The last-formed tangential band of fibers is located approximately 0.25 mm from the cambium zone. These types of cells are bordered radially by homogeneous phloem rays which are generally 1-3 seriate.

SPECIFIC GRAVITY, EXTRACTIVES AND FIBROUS YIELD

Basic information on such bark properties as specific gravity, level of extractives, fiber yield and the presence of such morphological elements as phloem fibers and phellem cells are expected to be useful in determining the need and possible methods of separating and segregating wood/bark chip mixtures.* Wherever possible, data on bark have been compared with similar information on wood.

Specific Gravity

Table XX summarizes the information available on wood and bark of white ash. Specific gravity is most often expressed in terms of ovendry weight divided by green volume. It should be noted that one of the values in the table is ovendry weight divided by ovendry volume. Information expressed in terms of green weight divided by green volume is useful when examining the possibilities of liquid flotation as a means of segregating wood/bark chip mixtures. Information in this report, under the section Water Flotation Behavior, compares the basic density (green weight divided by green volume) of white ash at several moisture contents.

*Throughout this report the term separation has been used to designate separation or detachment of wood from bark while segregation has been used to indicate removal of either the bark or wood fraction from wood/bark chip mixtures.

TABLE XX

WHITE ASH SPECIFIC GRAVITY INFORMATION

(Ovendry weight/green volume)

Wood Av.	Bark Inner	Bark Outer	Bark Total	Reference and Remarks
0.58				Bendtsen and Ethington (22)
0.56 (sapwood)			0.66	Choong and Cassens (31)
0.58			0.40	Manwiller (25)
0.58				
0.55				IUFRO (4)
			0.48	Murphey, et al. (34)
0.59 (exterior) 0.62 (interior)	0.53	0.41	0.47	IPC 3212-112
0.53 (exterior) 0.55 (interior)	0.50	0.45	0.49	IPC 3212-113
			0.51[a]	Harkin and Rowe (6)

[a]Ovendry weight and volume.

An average specific gravity (ovendry weight/green volume) of approximately 0.57 appears appropriate for the wood of white ash. Our samples were divided into interior and exterior wood and specific gravity determinations made on each. For 3212-112 the interior wood constituted the first 36 rings out of a total 70 rings and the first 33 rings out of a total 71 rings for 3212-113. Our limited data show the interior wood to be higher in specific gravity than the exterior wood.

The specific gravity of the total (inner + outer) bark of white ash is somewhat lower than that of the wood. The outer bark is slightly lower in specific gravity than the inner bark. Overall values suggested for use in species comparisons are 0.57 for wood and 0.52, 0.43, and 0.50 for inner, outer, and total bark.

Extractives

Extractives in wood and bark are important because, when present in large amounts, they not only result in reduced yield of fibrous material but ultimately can be expected to result in paper machine "pitch problems." Recent needs to reduce total water use through closed white water systems are expected to accentuate problems in this area. No attempt has been made in this report to go beyond determining the total alcohol-benzene extractives. Such extractives information is expected to provide an appropriate indication regarding possible pitch problems when large amounts of bark are pulped. Further detailed examination of the types of extractives involved is recommended using specific bark sources if preliminary comparisons suggest pitch and yield problems may develop.

Little information exists on the alcohol-benzene extractives of either white ash wood or bark. Table XXI summarizes existing data and includes the two IPC trees examined. White ash wood is low in extractives and a level of 4.0% is suggested for use in between-species comparisons. Extractives work done on white ash bark in this project plus an additional value showed an average level of 12.8%. This is a relatively high level compared to other hardwoods examined in this project. However, it should not be a serious problem except in those instances where high percentages of bark have been concentrated in a particular chip fraction by screening or other mechanical techniques.

Fibrous Yield

Increasing emphasis is being placed on pulping bark rather than debarking bolts or segregating wood/bark chip mixtures. Important to determining the usefulness of this approach with a particular species is determining the proportion of lignified cells that exist in the bark and that will survive normal cooking procedures. Also, it is important to determine what percentage of these cells will contribute in a favorable way to the resulting paper product.

TABLE XXI

WHITE ASH ALCOHOL-BENZENE EXTRACTIVES

Type of Material	Extractives, %	Sources
Wood	4.8	IPC 3212-112
Wood	3.2	IPC 3212-113
Bark	13.2	Murphey, et al. (34)
Bark	14.2	IPC 3212-112
Bark	11.0	IPC 3212-113

In the inner bark of some species there occur bands of heavily lignified fibers described in the literature as phloem fibers or sclerenchyma fibers. These fibers are the principal bark elements to survive chemical pulping and contribute to overall pulp yield and sheet strength. Phloem fibers are one of the principal elements found in pulped white ash bark.

The short, thin-walled sieve tubes that survive the pulping operation could be used as filler material in paper. However, it is questionable, other than an increase in pulp yield, whether they would contribute in any useful way to paper properties. When subjected to beating, they probably would not fibrillate to any appreciable extent. A sheet of paper, made entirely of sieve tubes, would probably be extremely brittle and low in strength. Sieve tubes could also conceivably contribute to felt plugging and drainage problems if built up in sufficient quantities through the use of a closed system. More work is needed in this area to determine the seriousness of this problem.

Sclereids occur in very minor quantities in white ash bark. They are short, thick-walled, heavily lignified cells and, when not fully cooked, as could occur in high-yield pulping, clumps of sclereids may cause so-called "fish eyes" in certain grades (calendered) of paper. However, the level of sclereids in white ash is so low they should cause no problem when the bark of this species is being pulped.

As a check on pulp yield and the nature of the material produced from white ash, 20 to 30-gram samples were pulped using the IPC Standard Kraft Micropulping Procedure. Table XXII summarizes the results of this investigation. Micropulping of white ash bark resulted in a yield of 35.0 to 36.3% solids. When screened, the coarse screens (60- and 100-mesh) retained mostly phloem fibers and a very small amount of other elements. The on 150-mesh screen retained large percentages of phloem fibers and sieve tubes. The on 200-mesh and through 200-mesh screens contained mainly sieve tubes and parenchymatous and peridermal cells. Figure 18 illustrates the type of material on the 60- and 150-mesh screens.

Based upon very limited numbers of bark sample observations, it appears that, for every 100 grams of bark that is pulped, an average of 35.7 grams of solids will result. Of this 35.7 grams, about 15.8 grams (15.8%) of phloem fibers and 0.1 gram (0.1%) of sieve tubes will be produced. This assumes that only the material on the 60- and 100-mesh screens would end up in and contribute in any significant way to the final product. The remaining material would be lost in washing and cleaning operations.

TABLE XXII

WHITE ASH MICROPULPING INVESTIGATIONS

Data	Sample No. 3212-112	Sample No. 3212-113	Remarks[a]
Yield, % solids	35.0	36.3	
Fraction			
on 60 mesh, %	30.1	52.7	The fraction contained principally phloem fibers (95+%) with a small percentage of peridermal and parenchymatous cells (<5%). Average arithmetic fiber length was 1.12 mm.
on 100 mesh, %	8.5	2.4	The fraction contained principally phloem fibers (90-95%) with small percentages of sieve tubes (<5%) and peridermal and parenchymatous cells (<5%) and a trace of sclereids (<1%).
on 150 mesh, %	4.9	1.9	The fraction contained large percentages of phloem fibers (50-60%) and sieve tubes (30-40%), with small percentages of peridermal and parenchymatous cells (<5%) and sclereids (<5%).
on 200 mesh, %	3.8	3.7	The fraction contained a large percentage of sieve tubes (60-70%) with small percentages of phloem fibers (10-20%), peridermal and parenchymatous cells (10-20%) and sclereids (5-10%).
through 200 mesh, %	52.7	39.3	The fraction contained principally peridermal and parenchymatous cells (90-95+%) with small percentages of phloem fibers (<5%), sieve tubes (<5%) and sclereids (<5%).

[a]Percentages in each fraction on a weight basis.

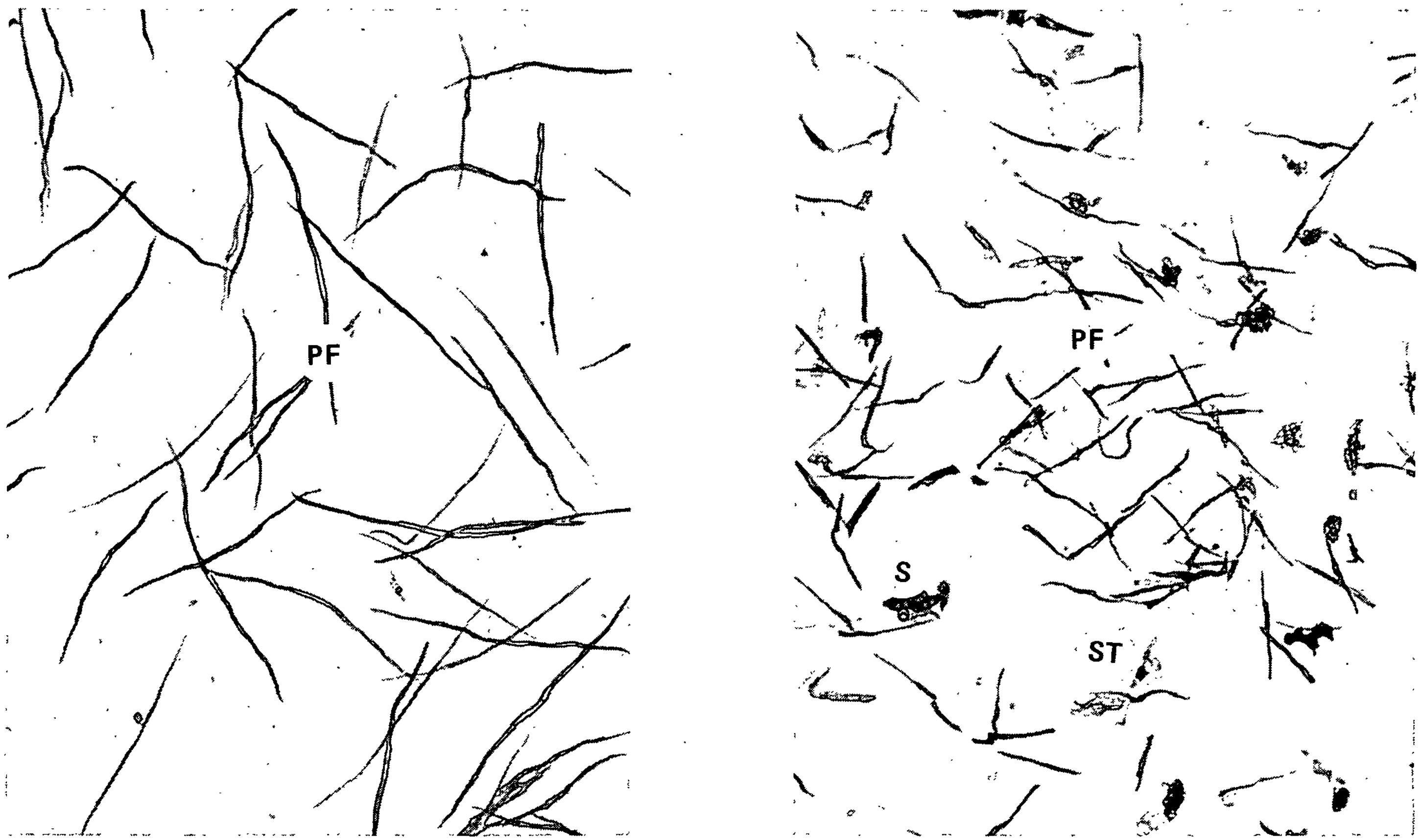


Figure 18. The 60-Mesh Screen (Left) Contained Principally Phloem Fibers (95+%). The 150-Mesh Screen (Right) Contained Large Percentages of Phloem Fibers (50-60%), Sieve Tubes (30-40%) and Sclereids (<5%). Magnification — 30X. Symbols Illustrate Phloem Fibers (PF), Sieve Tubes (ST) and Sclereids (S)

WOOD/BARK ADHESION

Wood/bark adhesion differences have been suggested as one of the reasons for the differences encountered in the ease of debarking pulpwood species. The same factors influencing debarking of pulpwood are expected to influence debarking of wood chips. The approach taken in the study was to obtain growing season and dormant season information on: (1) magnitude of wood/bark adhesion, (2) morphological structures associated with wood/bark adhesion, and (3) reasons for differences between species in adhesion.

Wood/bark adhesion values were measured for white ash samples collected March 15 (dormant season). Growing season measurements were discontinued after measurements were completed on twenty species, both conifers and hardwoods located throughout the United States, when little variation was encountered in adhesion values (3-6 kg/cm^2). Growing season failure zones quite consistently were located in the cambium zone or the newly formed xylem elements just outside the cambium zone.

Using the sampling and testing procedures described in the section on Experimental Procedures in Report One, shear parallel to the grain was measured. After testing, the samples were examined to determine the location of the zone of failure. Figure 19 illustrates the zone of failure for white ash during the dormant season. Failure occurred in the secondary phloem (inner bark) between sieve tubes and phloem parenchyma cells located approximately 0.3 mm from the cambium zone. Adhesion measurements averaged 23.8 kg/cm^2, a very high value.

As a result of measurement data taken on the species included in Appendix Table XXXII and the measurement data reported in the previous reports for this project, it is clear that dormant season wood/bark adhesion is related to inner bark strength and inner bark strength is in turn related to inner bark morphology. The presence of phloem fibers in the inner bark of hardwoods appears to be associated with high dormant season wood/bark adhesion. This is the case with white ash (adhesion value of 23.8 kg/cm^2). High numbers of sclereids and/or a lack of phloem fibers seem to be associated with low bark strength. Low dormant season wood/bark adhesion for the conifers investigated appears to be due primarily to the lack of fibers in the inner bark.

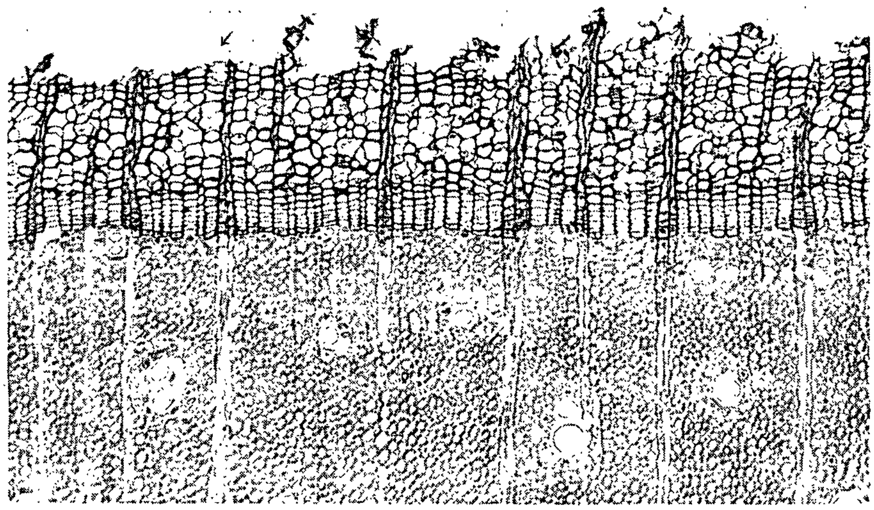


Figure 19. Illustrated is the White Ash Failure Zone on March 15. Failure Occurred in the Inner Bark Between Sieve Tubes and Phloem Parenchyma Approximately 0.3 mm from the Cambium Zone. Magnification — 75X

Separation (breaking the bond between bark and wood in a chip) is an important first step in segregation (removal of bark particles from wood chips). Separation during the growing season, when wood/bark adhesion is low, can usually be accomplished by the action of the chipper. During the dormant season, adhesion is greater and separation by chipper action is less successful.

Wilcox, et al. (35) did a study on the peeling characteristics of several species, including white ash. The other seven species investigated started to peel between April 23 and May 5 but white ash began peeling before April 16.

BARK STRENGTH, TOUGHNESS AND REACTION TO HAMMERMILLING

Bark strength and toughness measurements are included as part of the characterization of bark because it was felt that, when these measurements are compared with the results obtained in wood/bark adhesion tests, with the difficulty encountered in conventional debarking and with bark morphology, the "why" of bark separation and segregation would eventually emerge.

Hammermilling has been widely used in bark utilization to prepare fractions for use as horticultural mulch, soil conditioners, and as additives to a number of types of products. Hammermilling has been suggested as one step in a wood/bark segregation procedure. A simulated hammermilling test was developed in an effort to relate the hammermilling of bark (and wood) to bark strength, toughness and morphology.

As discussed in the section on Experimental Procedures (Progress Report One), bark strength measures shear parallel to the grain while bark toughness measures the energy required to rupture a thin specimen by a bending force perpendicular to the grain (parallel to the tree diameter). Table XXIII summarizes the bark strength and toughness tests made on the wood and bark of white ash. Appendix Tables XXXIV and XXXV compare the modulus of elasticity of white ash bark with other species examined in this project.

TABLE XXIII

SUMMARY OF STRENGTH AND TOUGHNESS MEASUREMENTS
MADE ON WOOD AND BARK OF WHITE ASH[a]

Material	Strength	Toughness
Wood	--	0.68
Inner bark	20.0	0.45
Outer bark	4.2	0.20

[a]Determinations average of two different trees.

Bark strength values for white ash inner bark were high compared to other hardwoods tested thus far. Outer bark strength was low. Toughness values for both wood and bark were high compared to other hardwoods tested. There appears to be a relationship between specific gravity, toughness and strength of the bark and bark removal by hammermilling. High specific gravity and low toughness and strength results in good bark removal while low specific gravity and high toughness and strength gives poor bark removal. Based upon the intermediate specific gravity and high toughness and inner bark strength measurements, it appears that hammermilling or other mechanical separation and segregation would not work well on this species.

Summarized in Table XXIV are the results of the hammermilling tests run on white ash wood and bark. Pure fractions of either wood or bark were fed into the hammermilling apparatus, caught in a cloth bag and screened. Hammermilling, followed by screening, can be expected to result in only a very modest reduction in levels of bark. When the half-sized chips for the two trees investigated were hammermilled and the material on the 14-mesh screen retained, the result was a 6% wood loss and a 24% reduction in bark. This is a fairly low bark removal compared to many of the other hardwoods investigated thus far. The low bark removal was expected, however, based upon the toughness and strength tests. A

TABLE XXIV

SUMMARY OF HAMMERMILLING TEST ON WHITE ASH

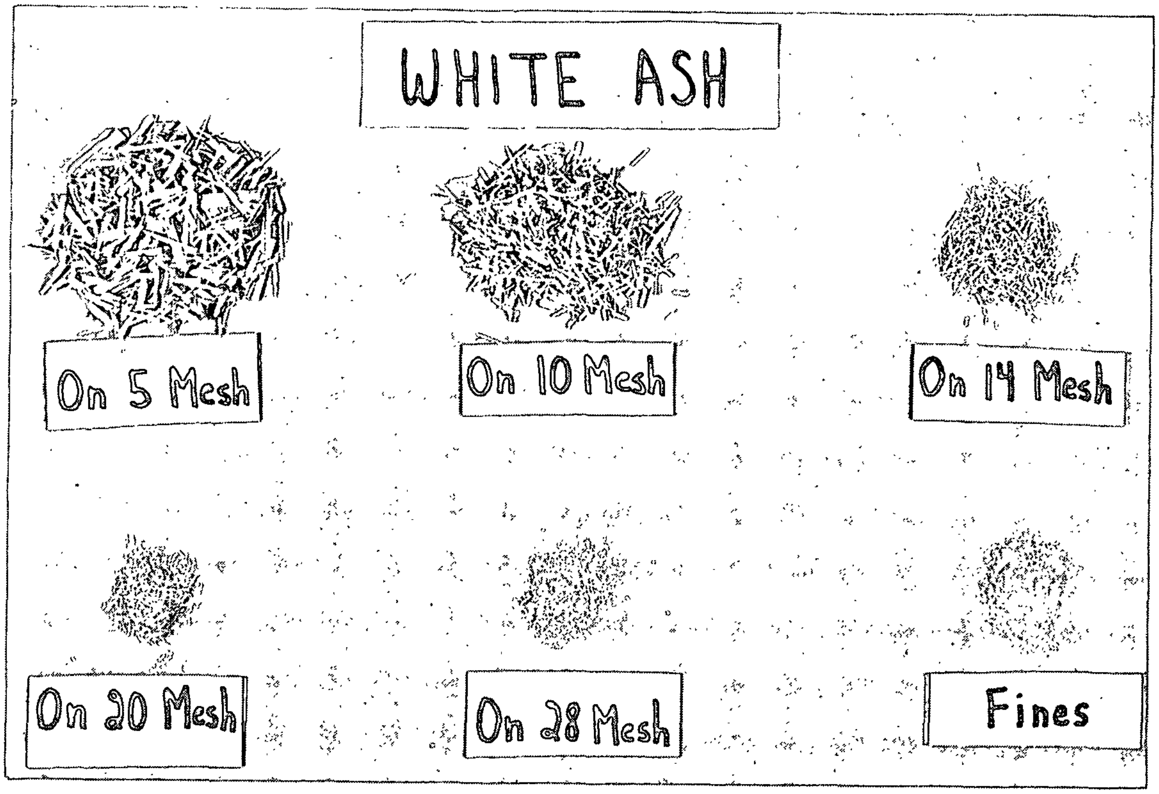
Tree No.	Material	Fraction Retained on Standard Screen[a], %						Remarks
		5 Mesh	10 Mesh	14 Mesh	20 Mesh	28 Mesh	<28 Mesh	
3212-112	Bark	38.7	27.6	8.8	4.5	5.7	14.7	A greater amount of inner than outer bark concentrated on larger mesh screens. More outer bark on smaller screens. Bark pieces long and slivery in appearance.
	Exterior wood	58.3	28.9	5.3	1.9	1.7	3.9	
	Interior wood	54.4	33.8	5.5	2.1	1.2	3.0	
3212-113	Bark	46.9	22.0	8.4	2.3	5.5	14.9	Same as 3212-112.
	Exterior wood	60.3	29.5	5.0	1.7	0.8	2.7	
	Interior wood	65.8	27.1	4.0	0.9	0.6	1.6	

[a]Standard soil screen sizes; 5 mesh has 5 wires per inch and an opening of 4.00 mm, 10 mesh has 10 wires per inch and an opening of 2.0 mm, 14 mesh has 14 wires per inch and an opening of 1.168 mm, 20 mesh has 20 wires per inch and an opening of 1.00 mm, and the 28 mesh screen has 28 wires per inch and an opening of 0.589 mm.

larger amount of bark (32%) could be removed by only retaining the material on the 10-mesh screen with an additional loss in wood of 4%. This additional 4% loss in wood might be acceptable in view of the increased amount of bark removed and the fuel value of the wood. Figure 20 illustrates the effect of hammermilling on wood and bark of white ash. It is possible that a quick segregation could be made by screening, hammermilling the fractions high in bark (small-sized chips) and rescreening. The fractions still remaining high in bark could be treated by some other method. It does not appear that changes in screen design would improve segregation results after hammermilling as the hammermilled bark is stringy and has a shape similar to that of the hammermilled wood. There would not be the differences in configuration of hammermilled wood and bark to use to advantage in screening. Summary Table XXX compares bark strength, toughness and reaction to hammermilling of white ash with other species tested thus far. The section on "Shredding of Chip/Bark Mixtures" compares hammermilling with shredding for both red pine and northern white oak.

WATER FLOTATION BEHAVIOR

One possible method of segregating wood/bark chip mixtures is by water flotation procedures. Knowledge of the flotation characteristics of wood and bark is expected to be important when certain types of chip washing procedures are employed. Earlier investigations into water flotation segregation (Project 2977) revealed that chip size, specific gravity, moisture content and rate of moisture uptake were factors in the flotation behavior of bark and wood chips. Budget limitations do not permit examination of all factors involved and, as a result, the influence of chip size has been eliminated from the variables considered.



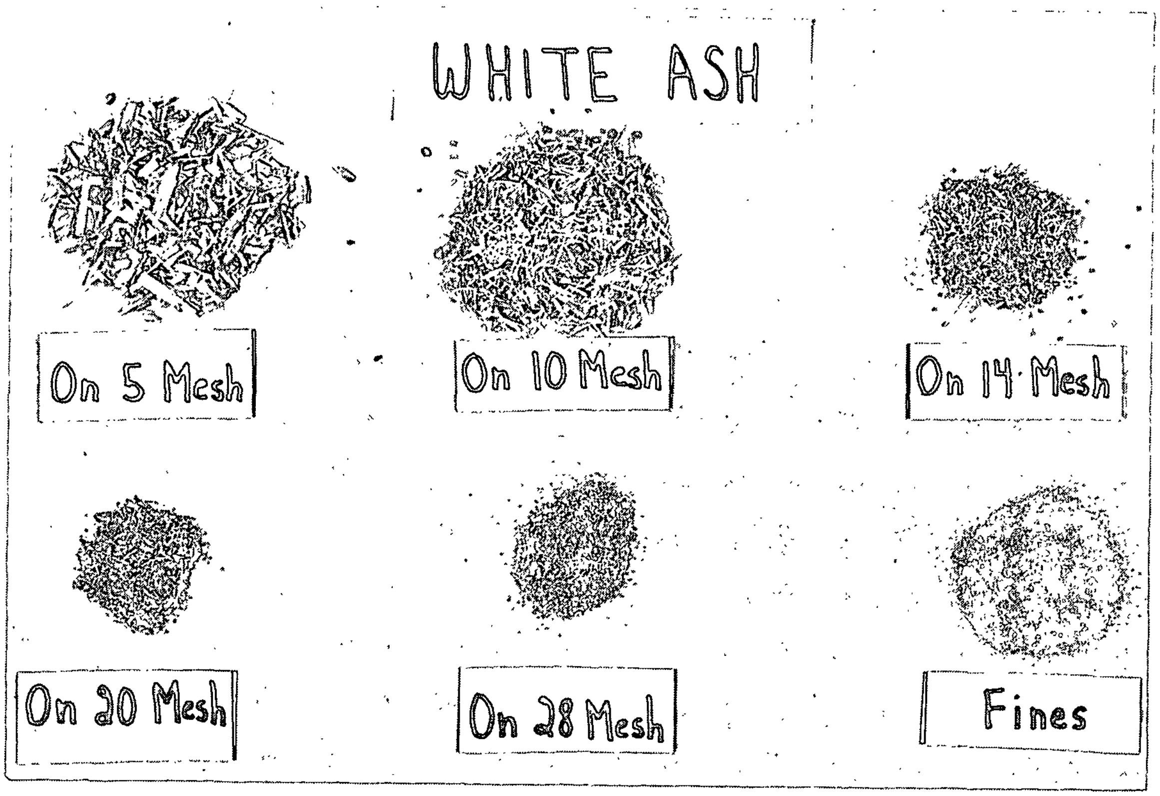


Figure 20. Illustrated is the Effect of Hammermilling on White Ash Wood (Top) and Bark (Bottom)

Two procedures were used to examine the water flotation behavior of wood and bark. One procedure involved measuring the density* (green weight divided by green volume) of simulated chips at a number of different moisture contents. The second technique involved measuring the rate of moisture uptake and sinking of wood and bark chips in what have been designated as "dwell time" studies.

Density Determinations

Simulated chips were used in determining the relationship between moisture content and density of bark and wood. Wood and bark from two white ash trees (IPC 3212-112 and IPC 3212-113) were used in making the determinations. The moisture content of the chip samples was adjusted by equilibrating in small jars to which had been added appropriate amounts of water. The extremely accurate pycnometer method described in the Experimental Procedures in Report One was used in determining density. Bark samples used were "whole bark" samples, a combination of both inner and outer bark. Small chips of inner and outer bark were also tested. The inner bark for both trees had a higher density than whole bark while outer bark, which makes up a slightly larger proportion of the bark by weight than does inner bark, is lower in density than both inner and whole bark.

Figure 21 illustrates the relationship that was found between moisture content and density. The linear relationship shown was obtained by fitting the least squares regression line through the data. The dashed lines are two standard deviations above and below the average values. The standard deviation of the regression line is considerably less than would have been obtained if conventional mill-run chips had been used for the water flotation studies, because the simulated

*The term density is used in this report to indicate the weight of wood and bark samples and is expressed in terms of green weight divided by green volume. This is in contrast to the term specific gravity, which also is an expression of the weight of a sample, but in this case it is in terms of dry weight divided by green volume.

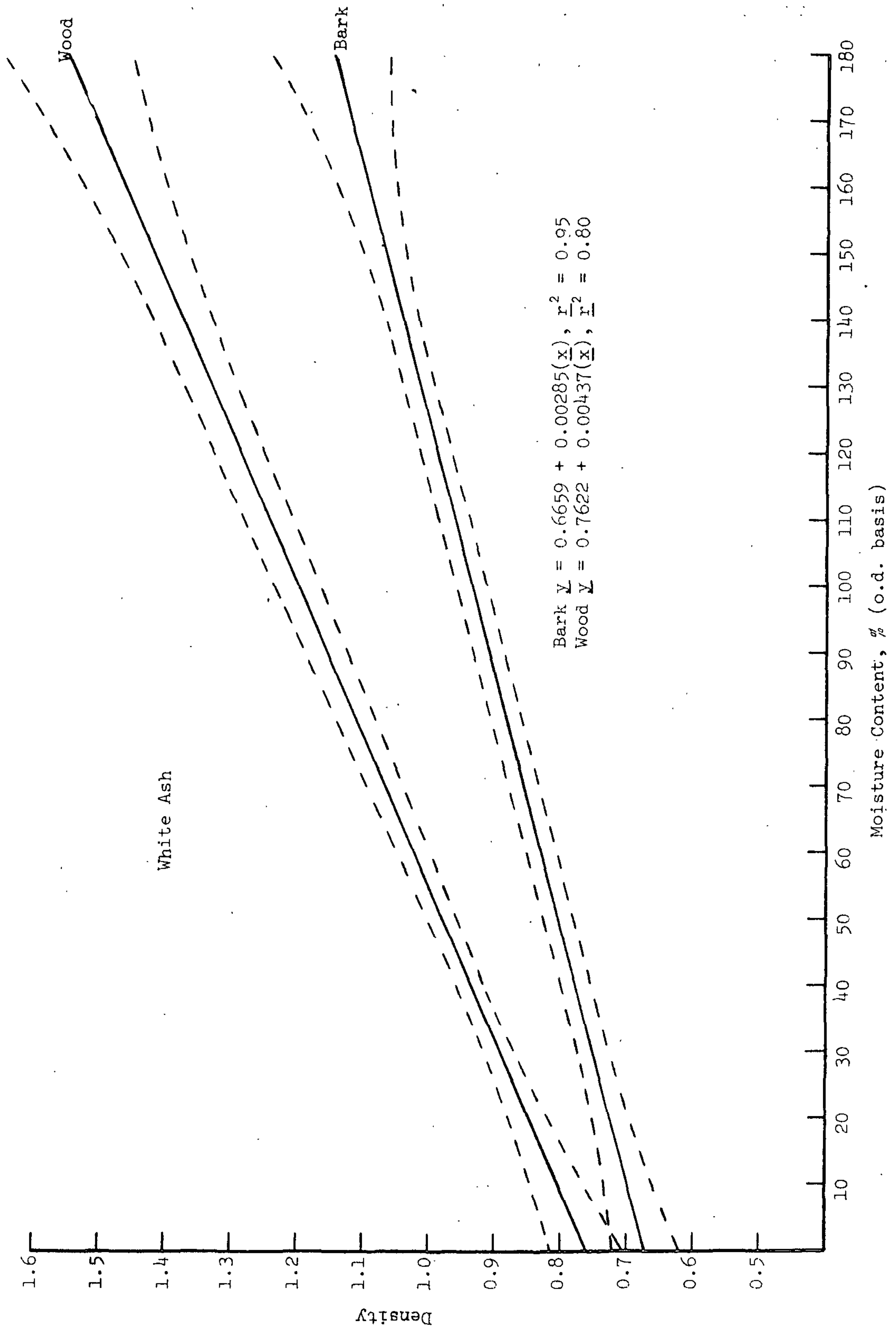


Figure 21. Illustrated is the Relationship Between Basic Density and Moisture Content for White Ash. The Dashed Lines are Two Standard Deviations Above and Below the Mean

chips were uniform in size and shape, had a uniform level of moisture and were relatively free of knots, reaction wood, etc. Water segregation is believed to be possible when one fraction has a density of less than one and the other greater than one at a specific moisture content.

The data indicate that at moisture contents between 60 and 110%, wood could be expected to sink (density greater than 1) while the bark would still be floating (density less than 1). This is a fairly good range of moisture contents to effect segregation and it appears segregation through water flotation is a feasible method for white ash.

Dwell-Time Investigations

An investigation of dwell time involves nothing more than taking wood and bark chips at some standard moisture content, placing them on a water surface and observing the time it takes the material to pick up enough water to sink. Information on dwell time is useful because moisture uptake rates could have a considerable influence on the success of a segregation procedure (or chip-washing procedure) and would provide information on the rate at which segregation could be expected. A species in which either the bark or the wood takes up moisture rapidly could be expected to have a relatively short segregation time. For other species, where specific gravity and density of the wood and bark are similar and moisture uptake is similar, considerable difficulty in segregation can be anticipated. Half-sized simulated chips (1 x 0.3 x 0.2 inch) were used in the dwell time tests. Prior to testing, the samples were equilibrated in 50% RH and had a moisture content of approximately 20% (ovendry basis). Table XXV summarizes the results for white ash. These results agree with the results obtained in the density determination measurements which showed both wood and bark floating at 20% moisture content. Detached inner and outer bark would probably behave in a similar manner.

TABLE XXV

SUMMARY OF DWELL TIME RESULTS FOR WHITE ASH[a]

Sample No.	Time Interval, min	Sinkers, %	Floaters, %
IPC 3212-112	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-112	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-112	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-113	after 5	0	100
Bark	15	0	100
	60	0	100
	240	0	100
IPC 3212-113	after 5	0	100
Exterior wood	15	0	100
	60	0	100
	240	0	100
IPC 3212-113	after 5	0	100
Interior wood	15	0	100
	60	0	100
	240	0	100

[a]Starting moisture content 20%.

DATA INTERPRETATION

Fiber yield from the bark of white ash is high and the level of sclereids is very low. Pulping white ash bark resulted in 15.8% phloem fibers and 0.1% sieve tubes being produced. This assumes that only the material on the 60- and 100-mesh screens would end up in the final product.

Since white ash is high in extractives, however, it may be desirable to remove at least part of the bark. White ash gave high adhesion values during the dormant season but, according to one researcher, the peeling season begins earlier than it does for many species.

The mechanical treatment investigated in this project to separate and segregate wood and bark, hammermilling, gave poor results with only a 24% reduction in bark levels and a 6% wood loss by retaining the material on the 14-mesh or larger screens. By only retaining the material on the 10-mesh screen, the result was a 10% wood loss and 32% bark removal, which is still rather low.

Segregation through water flotation proved to be a feasible technique with segregation possible at moisture contents of between 60 and 110% (o.d. basis). At these moisture contents, the wood would sink while the bark would still be floating.

White ash appears to be a species that could be handled with some success by first screening whole-tree chips to concentrate most of the bark in the small chip fraction (<3/8 inch), next mechanically treating (shredding or hammermilling) and rescreening that fraction to remove a modest amount of bark and reduce the grit and extractives problem and then pulping the remaining stringy, fiber-rich bark.

RELATED LITERATURE

There are a number of papers on the economics and mechanics of segregating bark mixtures. They include papers by Auchter and Horn (14), Hooper (15) and Biltonen, *et al*. (16). Wood and bark moisture contents of white ash and several other hardwoods are discussed in a paper by Manwiller (33).

BARK FUEL VALUE, ASH, CALCIUM, AND SILICA LEVELS

FUEL VALUE

Rising fuel prices have prompted a closer look at the use of bark as fuel. For many end products, removal of the bark is necessary and utilization of bark as fuel is a partial solution to disposal of bark waste.

Listed in Table XXVI are the Btu values of the species investigated thus far, both in terms of Btu's per ovendry pound and Btu's per cubic foot. Although values are quite similar when figured on the basis of Btu's per ovendry pound, the relative fuel value of the various species becomes more apparent when the specific gravity of the bark is taken into account and heating value is figured in terms of pounds per cubic foot. Also given in Table XXVI are values found in the literature. In most cases, the values found in the literature have been converted to pounds per cubic foot for comparison with IPC values.

Chang and Mitchell (32) reported that the heating value of hardwood barks was lower than that of softwood barks. They found that the barks of all eight softwood species investigated had values greater than 8500 Btu's per dry pound and nine of twelve hardwoods had lower values. However, hardwood barks, on the whole, are higher in specific gravity than softwoods and, when this is taken into account by calculating the values on a cubic foot basis, the fuel value of hardwood barks is generally greater than that of softwood barks.

Fuel value is extremely sensitive to moisture content. Green wood of most species has about 60% of the heat value of well air-dried wood. For instance, a pound of oven-dried red oak wood with a calorific value of 8600 Btu's yields about 5700 Btu's when air dried and about 3400 Btu's when green (36). Figure 22,

TABLE XXVI

BARK FUEL VALUES

Species	Total Sp.Gr.	Weight, lb/ft^3	Btu/lb o.d. wt.	Btu/ft^3	Literature Values, Btu, lb/ft^3[a]
Quaking aspen	0.50	31.2	8,712	271,814	318,041 (39), 263,110 (32)
Sugar maple	0.54	33.7	8,426	283,956	299,572 (39), 246,044 (32)
White birch	0.56	34.9	10,332	360,587	371,160 (39), 329,247 (32)
Northern red oak	0.65	40.6	8,896	361,178	320,090 (25)
Southern red oak	0.70	43.7	8,371	365,813	349,250 (25)
Northern white oak	0.58	36.2	7,536	272,803	
Southern white oak	0.56	34.9	8,046	280,805	256,271 (25)
Eastern cottonwood	0.31	19.3	8,422	162,545	
Sweetgum	0.42	26.2	7,650	200,430	188,640 (25), 195,190 (32)
Yellow poplar	0.38	23.7	8,956	212,257	
Black tupelo	0.44	27.5	8,102	222,805	
Sycamore	0.60	37.4	7,978	298,377	
White ash	0.50	31.2	8,453	263,734	
Loblolly pine	0.33	20.6	9,320	191,992	193,640 (40)
Slash pine	0.35	21.8	9,327	203,329	196,244 (32), 204,484 (40)
Douglas-fir	0.41	25.6	9,962	255,027	252,595 (38), 258,560 (41)
Western hemlock	0.45	28.1	9,297	261,246	262,735 (38)
Engelmann spruce	0.51	31.8	8,830	280,794	265,816 (32)
Lodgepole pine	0.38	23.7	9,382	222,353	241,503 (32)
Ponderosa pine	0.35	21.8	9,616	209,629	
Western larch	0.32	20.0	8,825	176,500	164,080 (32)
White spruce	0.39	24.3	8,913	216,586	241,399 (39)
Balsam fir	0.40	25.0	9,339	233,475	281,190 (39), 221,525 (32)
Jack pine	0.41	25.6	9,393	240,461	299,155 (39), 224,282 (32)
Red pine	0.27	16.8	9,070	152,376	
Shortleaf pine	0.35	21.8	9,310	202,958	208,190 (40)
Longleaf pine	0.45	28.1	9,290	261,049	256,553 (40)
Virginia pine	0.54	33.7	9,170	309,029	283,889 (41)

[a]Literature cited [Chang and Mitchell (32)] values based on airdry samples with an average moisture content of 6% (range 4.8 to 6.7%).

taken from data supplied by Cunningham and De Vriend (37) shows the drop in usable Btu's at increasing moisture contents.

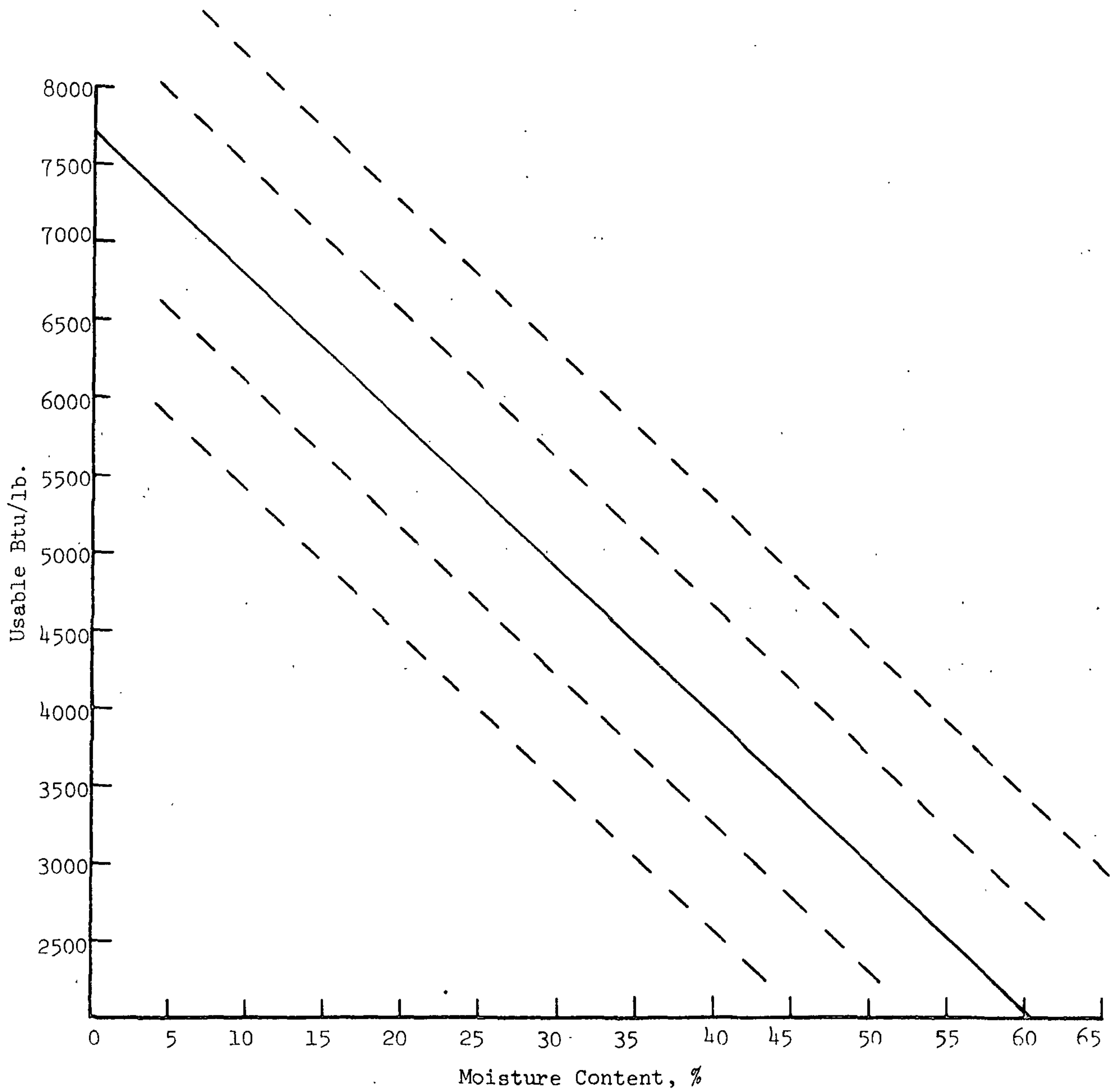


Figure 22. Illustrated is the Effect of Moisture Content on Usable Btu's per Pound

ASH, CALCIUM, AND SILICA LEVELS

Listed in Table XXVII are percent ash, calcium and silica on an oven-dry basis. Ash is the noncombustible part of the bark and needs to be removed, at least in part, after burning. According to Chang and Mitchell (32), a high percentage of ash tends to give lower heat of combustion values. Wood has a low ash content, generally less than 1% of dry weight (38). IPC ash values for bark ranged from 0.8% for loblolly and slash pine to 12.6% for northern white oak. Softwoods generally had lower ash values than did hardwoods. Also listed in Table XXVII are values obtained from the literature.

Calcium is one of the principal inorganic elements in bark. When bark is pulped, high levels of calcium can be expected to increase recovery system scaling problems. More rapid scaling increases evaporator down time and reduces heat transfer. Low percentages of calcium in bark are therefore desirable. Trends were the same for percent calcium with loblolly and slash pine again the lowest of the species investigated (0.2%) and northern white oak the highest (5.2%). Also, as with percent ash, softwoods generally had lower values than did hardwoods.

Insoluble silicates are naturally occurring minerals that are commonly found in soils. They include not only extremely hard and abrasive types of minerals but silicon as an element in clay minerals of soils. Silica (SiO_2) levels are of interest because, in the form of minerals, they represent the principal acid insoluble fraction in bark and, as such, are expected to remain as one possible abrasive contaminant in pulps.

The SiO_2 levels reported in Table XXVII are levels from bark samples which have been carefully harvested and transported and represent SiO_2 levels in bark

TABLE XXVII

PERCENT ASH, CALCIUM AND SILICA IN BARK

Ovendry Basis

Species	Ash, %[a]	Literature Values, ash, %	Calcium, %	Silica, %
Quaking aspen	5.2	2.8 (32), 3.9 (39)	1.9	0.03
Sugar maple	8.3	6.3 (32), 5.0 (39)	3.0	0.19
White birch	2.4	1.5 (32), 1.7 (39)	0.7	0.06
Northern red oak	5.4	5.4 (32)	2.2	0.12
Southern red oak	6.5		2.6	0.14
Northern white oak	12.6	10.7 (32)	5.2	0.29
Southern white oak	8.2	10.7 (32)	3.4	0.42
Eastern cottonwood	6.2		2.5	0.18
Sweetgum	10.5	5.7 (32)	3.8	1.41
Yellow poplar	2.8		1.0	0.05
Black tupelo	7.3		2.9	0.11
Sycamore	7.1		3.0	0.06
White ash	4.4		1.6	0.13
Loblolly pine	0.8	0.4 (40)	0.2	0.09
Slash pine	0.8	0.6 (32) 0.7 (40)	0.2	0.04
Douglas-fir	1.2		0.3	0.06
Western hemlock	1.7		0.3	0.04
Engelmann spruce	2.6	2.5 (32)	0.8	0.08
Lodgepole pine	2.2	2.0 (32)	0.6	0.16
Ponderosa pine	0.7		0.2	0.16
Western larch	2.4	1.6 (32)	0.6	0.26
White spruce	4.2	3.5 (39)	1.2	0.14
Balsam fir	3.4	2.3 (32), 2.6 (39)	1.0	0.10
Jack pine	1.3	1.7 (32) 2.1 (39)	0.3	0.14
Red pine	1.3		0.3	0.03
Shortleaf pine	1.6	0.7 (40)	0.4	0.10
Longleaf pine	0.6	0.7 (40)	0.2	0.004
Virginia pine	2.2		0.7	0.01

[a]Ashed at 600°C.

relatively free from contaminating soil minerals. Some measure of silica levels (principally sand) that are added by harvesting and transporting could be obtained by comparing appropriately sampled and analyzed wood and bark samples from company operations with the relatively soil-free silica (SiO_2) levels reported in Table XXVII.

There has been greatly increased interest in bark Btu's, calcium, ash and silica content, resulting in a number of publications in this area. Additional publications of interest include those by Corder (41,42), Junge (43,44), Howard (45), Johnson (46), Smith (47), Burnett (48) and Kowalczyk (49).

SHREDDING OF CHIP/BARK MIXTURES

The results of a chip shredding experiment were reported in Project 3212, Progress Report Six. Two unbarked bolts of red pine were chipped and screened through 2-, 4- and 10-mesh screens. The material that fell on the 2-mesh screen was relatively free of bark (3%) and could be pulped as is. The 4-mesh material contained 24% bark and that fraction was shredded and rescreened. Discarding, possibly for fuel, all material that was retained on the 10-mesh screen or finer, the end result was a 9% wood loss and 8% bark contamination in the wood recovered to be pulped.

It was decided to try the same procedure on a hardwood to determine if it would react in a different manner to shredding. Northern white oak was selected as the species to be used because of its availability, high wood and bark specific gravity and moderate bark toughness and strength.

Benefits associated with shredded wood include: increased yields, lower chemical consumption and either reduced cooking temperature and/or lower cooking times (50,51). Shredding is reported not to have affected pulp strength properties of sulfate and bisulfite pulps. Some reduction in tear has been reported for acid sulfite pulps. Shredding is also expected to dislodge the attached grit and result in removal of a considerable part of this type of material when the chips are screened.

The samples were air-dried bolts collected June 17 from two trees 7.7 inches in diameter at bh and 57.5 feet tall and 8.1 inches dbh and 56 feet tall. The amount of bark averaged 14.5% on the bolts and included approximately half inner and half outer bark or perhaps slightly more outer bark. After the bolts were chipped, the bark in the chip mixture amounted to 10.7%. The difference between the amount of bark on the bolts and the bark in the chip mixture may be due to the selection of bolts for chipping. The bolts were randomly selected and possibly were the lower bolts which contain a lower percentage of bark. Also, some bark could have been lost during handling while chipping.

In the first experiment, four bolts were chipped (2 bolts each from 2 trees) and screened. Fines and oversized material were removed. The rest of the chips were separated into three fractions: wood, bark and bark with wood attached. Each fraction was screened and the percentage on each screen calculated. Screen sizes included 2, 4 and 10 mesh. The chip sizes that made up each fraction were then recombined, shredded and rescreened. Before shredding, 99.7% of the wood was retained on the 2- and 4-mesh screens while for the bark 96.4% remained on the 2- and 4-mesh screens. After shredding, 72.5% of the wood remained on the 2- and 4-mesh screens and for the bark 35.9% was retained. (Material on the 10-mesh screen or finer was considered as fines.) The samples were run at a moisture content (dry weight basis) of 49% for the wood and 18.5% for the bark. The moisture content was that of chips from bolts that had been air dried for one and one-half months.

In the second procedure, two bolts were chipped (1 bolt each from 2 trees). The wood/bark chip mixture was screened and only the material on the 4-mesh screen was shredded. This was the fraction highest in bark. (Again, the material on the 10-mesh screen or finer was considered fines.) Figure 23 is a flow diagram which shows the breakdown of the various fractions and how they could be treated. The end result of this experiment was a 5% wood loss and 6% bark contamination in the wood recovered to be pulped. This flow diagram may be compared to the flow diagram for red pine in Progress Report Six, p. 114. Figure 24 illustrates the appearance of white oak wood and bark before and after shredding.

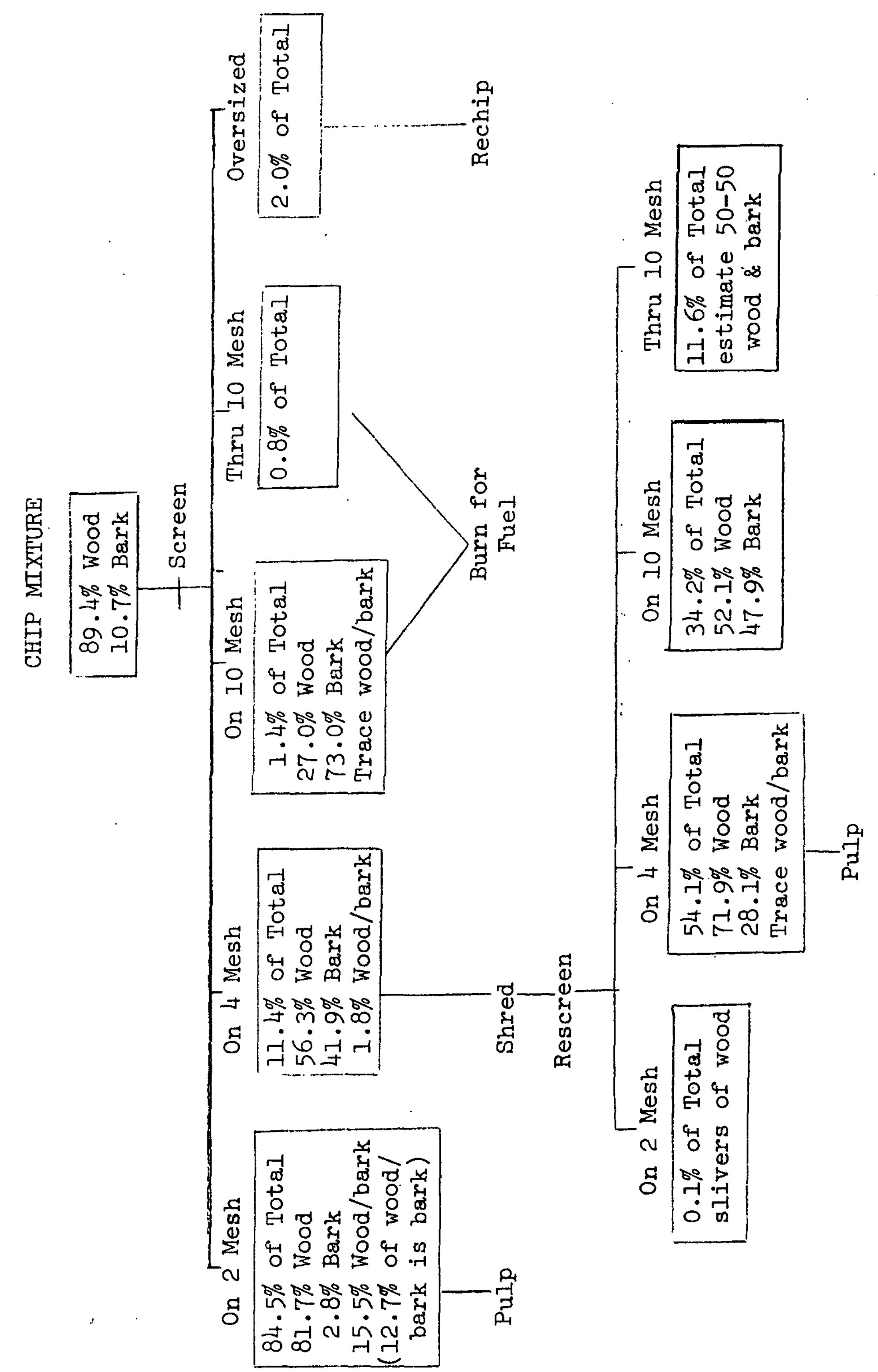


Figure 23. Flow Diagram of Shredding Procedure for White Oak

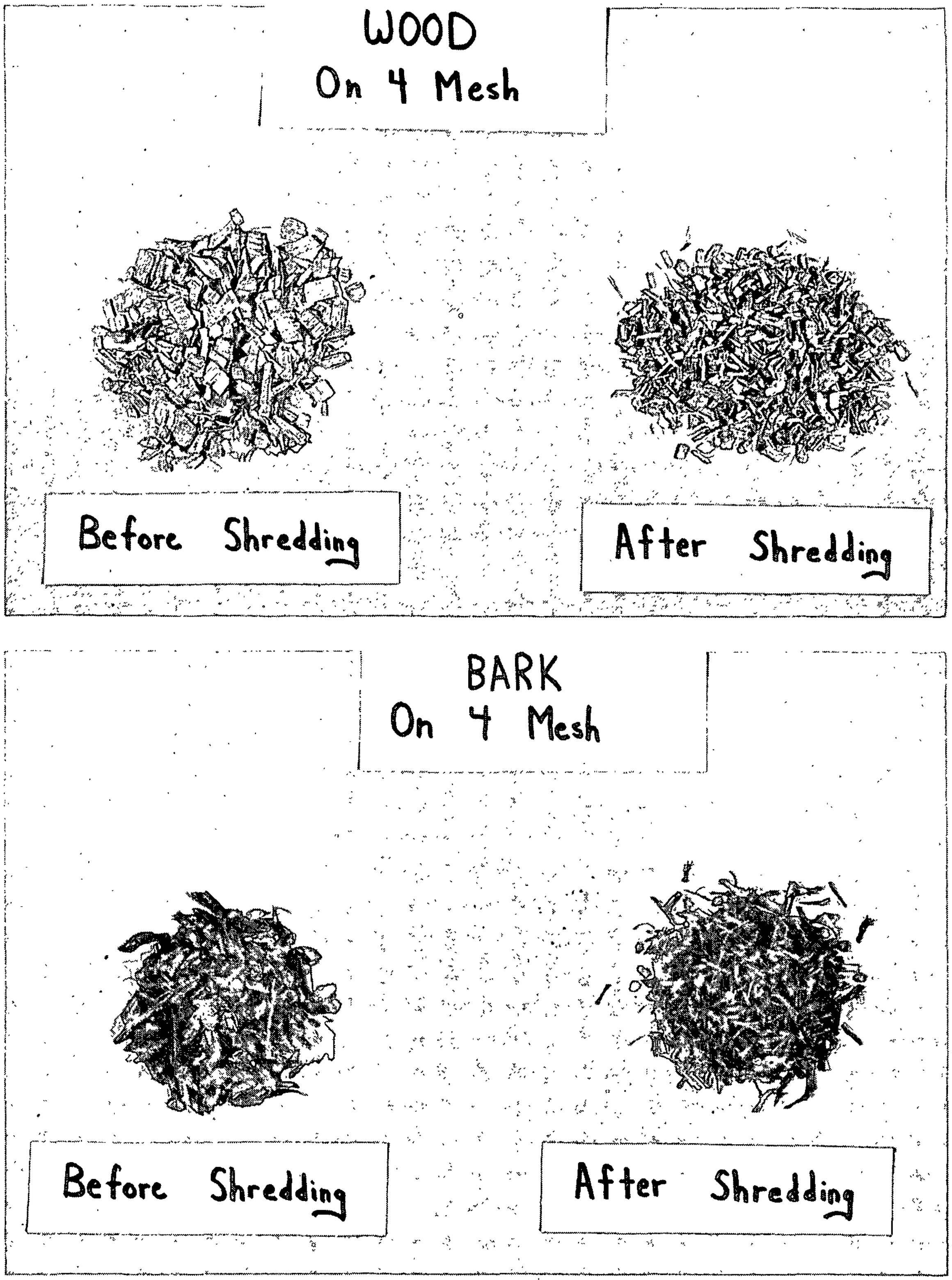


Figure 24. Illustrated is the Appearance of White Oak Wood and Bark Before and After Shredding

The results were better for northern white oak than they were for red pine although they were encouraging for both species. Table XXVIII summarizes the results of the shredding experiments. Wood loss through shredding was minimal and bark contamination relatively low, although not reduced greatly from the original amount of bark in the chip mixtures. If the shredding results are compared to the simulated hammermilling results by retaining the material on the 5-mesh screen for hammermilling and the 4-mesh screen for shredding, the advantage of shredding can readily be seen. (It must be remembered when comparing the two that the shredding experiment dealt with a natural chip mixture while the hammermilling experiments utilized pure fractions of simulated chips.)

TABLE XXVIII

SHREDDING AND HAMMERMILLING COMPARISON, %

Species	% Bark in Original Chip Mixture	Shredding — On 4 Mesh		Hammermilling — On 5 Mesh	
		Wood Loss	Bark Contamination	Wood Loss	Bark Contamination
Red pine	12	9	8	52	78
White oak	11	5	6	23	71

Besides the previously mentioned advantages of shredded wood for pulping, it is possible that this action would remove a lot of the grit and dirt which contributes heavily to equipment wear. In addition, the degree of shredding can be adjusted, depending upon the species involved. With experience, adjusting the equipment could possibly result in even better bark removal and less wood loss. Another advantage of shredding is that, based upon our limited work, moisture content does not appear to be a critical factor in shredding. The material is easier to work with in an air-dried state and it is possible that results might be somewhat better because material would not cling together, but it does also work on freshly cut and chipped trees.

BETWEEN-SPECIES COMPARISONS

Between-species comparisons provide an opportunity to develop useful interrelationships between bark strength and bark morphology that should in turn improve our overall understanding of bark properties. Tables XXIX (conifers) and XXX (hardwoods) provide a brief summary of much of the important data available on the first twenty-eight species investigated. Data on wood/bark adhesion, bark strength, and modulus of elasticity are summarized in Appendix Tables XXXII, XXXIII, XXXIV, and XXXV. Table XXVI, summarizing bark fuel values, and Table XXVII, dealing with ash content, are located in one of the last sections of the report and serve as an additional source of useful data.

Between-species comparisons in Progress Report Six summarized available information on conifers. Since Progress Report Seven deals with four species of hardwoods, and no new information is available on the conifers, the comments that follow will be confined primarily to the hardwoods that have been investigated to date by Project 3212.

For the species investigated, most conifer barks were lower in specific gravity than the hardwood barks (Engelmann spruce, Virginia pine, eastern cottonwood and yellow poplar are exceptions). The specific gravity of the hardwood barks investigated show no consistent relationship to the specific gravity of the associated sapwood. For some species, the wood has a higher specific gravity, for others the bark has the higher specific gravity and there are several species, like gum and yellow poplar, where the specific gravity of the wood and bark is very similar. Conifer barks are generally similar or lower in specific gravity than the associated sapwood (Engelmann spruce was an exception). The lack of a consistent specific gravity relationship in hardwoods makes the use of a water flotation procedure for mixed hardwood chips virtually impossible.

TABLE XXIX

WOOD AND BARK CHARACTERISTICS OF CONIFER PULPWOOD SPECIES

Characteristic	White Spruce	Balsam Fir	Jack Pine	Loblolly Pine	Slash Pine	Douglas-fir	Western Hemlock	Lodgepole Pine	Ponderosa Pine	Engelmann Spruce	Western Larch	Red Pine	Shortleaf Pine	Longleaf Pine	Virginia Pine
Specific gravity (o.d. wt./green vol.)															
Wood	0.34	0.34	0.39	0.45	0.54	0.43	0.40	0.39	0.39	0.34	0.50	0.39	0.47	0.55	0.50
Total bark	0.39	0.40	0.41	0.33	0.35	0.41	0.45	0.38	0.35	0.51	0.33	0.27	0.35	0.45	0.54
Inner bark	--	0.32	--	0.29	0.34	0.42	0.46	0.32	0.34	0.41	0.37	0.20	0.26	0.25	0.27
Outer bark	0.43	0.46	0.43	0.34	0.36	0.40	0.45	0.45	0.35	0.52	0.33	0.29	0.35	0.48	0.56
Extractives, %															
Wood	2.2	2.0	3.9	3.0	3.3	4.0	1.6	3.5	5.3	2.8	1.4	3.5	4.1	4.3	4.1
Bark	16.0	19.5	15.3	8.5	8.4	16.4	11.7	15.7	15.7	24.4	14.4	5.8	7.7	8.8	8.2
Density at 100% moisture (green wt./green vol.)															
Wood	0.70	0.75	0.79	0.86	1.10	0.815	0.80	0.89-0.92	0.96	0.80	1.43	0.74	1.10	1.20	1.08
Bark	0.83	1.07	0.83	0.57	0.72	0.825	0.85	0.74-0.95	0.62	1.14	0.61	0.62	0.72	0.90	1.03
Pulp yield, % (bark)	20.6	26.0	18.6	23.6	23.6	17.6	35.8	27.4	29.1	24.4	27.8	33.0	20.1	26.4	23.2
Usable bark fiber, %[a]	0	0	0	0	0	5	0	0	0	0	1	0	0	0	0
Sclereids or phellem cells remaining, %[a]	1.5	12.0	<1	1	2	2	11	<1	1	3	0	<1	<1	<1	<1
Fiber location[b]	--	--	--	--	--	IB-OB	--	--	--	--	IB	--	--	--	--
Sclereid or phellem cell location[b]	IB-OB	IB	OB	OB	OB	IB-OB	IB-OB	OB	OB	OB	--	OB	OB	OB	OB
Wood/bark adhesion, kg/cm^2															
Growing season	4.4	2.4	4.0	5.8	3.5	3.4	3.6	2.2	5.0	3.4	1.2	--	--	--	--
Dormant season	10.3	9.0	10.7	5.5	9.1	8.0	8.2	5.6	9.6	12.5	4.4	9.6	8.6	22.0[d]	7.2
Bark strength, kg/cm^2															
Inner bark	--	1.7	2.3	3.7	6.4	5.8	6.0	--	4.6	--	4.5	--	7.4	--	4.6
Outer bark	7.4	1.4	2.3	3.2	5.2	3.0	--	2.4	4.9	4.2	4.4	5.6	2.7	5.8	4.0
Toughness															
Inner bark	--	0.06	--	0.10	0.06	0.34	0.12	0.10	0.10	0.24	0.12	0.16	0.16	0.21	0.30
Outer bark	0.16	--	0.07	0.06	0.09	0.03	0.10	0.08	0.08	0.16	0.10	0.12	0.10	0.10	0.16
Sapwood	0.34	0.42	0.34	0.54	0.54	0.58	0.28	0.28	0.26	0.26	0.28	0.60	0.94	0.89	0.61
Hammermilling[c]															
Bark removed, %	23	44	26	34	36	28	24	31	26	25	26	26	29	35	31
Wood loss, %	4	6	5	6	5	4	3	4	4	4	6	5	4	6	4

[a] Usable bark fiber and sclereids or phellem cells remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.
[b] Major proportion located in either the inner bark (IB) or outer bark (OB).
[c] Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.
[d] Unusually high value which will be rechecked before the end of the project.

TABLE XXX

WOOD AND BARK CHARACTERISTICS OF HARDWOOD PULPWOOD SPECIES

Characteristic	Quaking Aspen	Eastern Cottonwood	Sweetgum	Sugar Maple	White Birch	Northern Red Oak	Southern Red Oak	Northern White Oak	Southern White Oak	Sycamore	Yellow Poplar	Black Tupelo	White Ash
Specific gravity (o.d. wt./green vol.)													
Wood	0.38	0.38	0.44	0.59	0.49	0.56	0.60	0.64	0.67	0.45	0.39	0.52	0.57
Total bark	0.50	0.31	0.42	0.54	0.56	0.65	0.70	0.58	0.56	0.60	0.38	0.40	0.48
Inner bark	0.40	0.29	0.51	0.69	0.57	0.53	0.68	0.65	0.70	0.60	0.38	0.37	0.51
Outer bark	0.55	0.32	0.36	0.49	0.54	0.71	0.70	0.52	0.44	--	0.42	0.37	0.43
Extractives, %													
Wood	3.0	1.4	2.6	1.0	4.0	4.5	4.8	2.4	4.6	2.2	3.9	3.0	4.0
Bark	15	7.9	10.2	6	17	11	11.6	7.2	8.6	8.1	13.8	10.6	12.6
Density at 100% moisture (green wt./green vol.)													
Wood	0.79	0.84	0.84	1.24	1.01	1.06	1.25	1.30	1.38	0.98	0.79	0.88	1.20
Bark	1.15	0.81	0.87	1.08	1.16	1.18	1.39	1.05	1.13	1.21	0.82	0.85	0.95
Pulp yield, % (bark)	33.8	35.4	34.9	33.9	36.3	28.4	30.7	35.4	36.6	31.4	32.3	31.4	35.7
Usable bark fiber, %[a]	10	9	5	3	0	5	4	3	3	0	13	1-10	16
Sclereids remaining, %[a]	1	<0.1	--	0.2	0.7	0.2	--	--	--	--	0	0	0
Fiber location[b]	IB	IB	IB	IB	--	IB	IB	IB	IB	--	IB	IB	IB
Sclereid location[b]	IB	--	IB	IB	IB	IB	IB-OB	IB-OB	IB-OB	IB	--	IB-OB	--
Wood/bark adhesion, kg/cm^2													
Growing season	6.4	4.4	10.2	5.8	5.1	2.5	5.4	4.8	--	--	--	--	--
Dormant season	11.4	13.5	15.3	10.1	12.0	8.4	8.2	7.8	7.2	14.8[e]	16.6	13.5	23.8
Bark strength, kg/cm^2													
Inner bark	9.0	17.7	8.1	1.4	1.6	2.1	3.6	4.6	4.7[d]	6.1	13.4	9.6	20.0
Outer bark	4.9	4.2	5.2	4.7	9.8	4.6	3.4	3.2	--	--	10.4	10.5	4.2
Toughness													
Inner bark	0.22	0.14	0.20	0.25	0.10	0.13	0.11	0.16	0.12	0.15	0.20	0.20	0.45
Outer bark	0.10	0.11	0.11	0.10	0.10	0.18	0.14	0.10	0.09	--	0.18	--	0.20
Sapwood	0.45	0.38	0.28	1.20	0.68	0.93	0.55	0.62	0.98	0.50	0.23	0.56	0.68
Hammermilling[c]													
Bark removed, %	34	18	32	29	38	34	46	37	38	45	23	39[e]	24
Wood loss, %	5	5	7	5	6	10	6	5	3	7	7	5	6

[a]Usable bark fiber and sclereids remaining are the fibers and sclereids retained on the 60- and 100-mesh screens. The percentage given is the yield based on whole bark samples.
[b]Major proportion located in either the inner bark (IB) or outer bark (OB).
[c]Based upon simulated hammermilling followed by screening, using the on 14-mesh screen to remove bark and recover usable fiber from fines.
[d]Test mistakenly performed on total bark.
[e]Samples failed in tensile.

Hardwood barks, with the exception of sycamore and white birch, have varying levels of fiberlike structures in the bark. Conifers, in contrast, with the exception of Douglas-fir and to a lesser extent western larch, contain no fiberlike elements in the bark. These results suggest that most conifer barks, when pulped, are not expected to produce fiber that will contribute to the strength of the paper and board being produced. There is also considerable evidence that the high amounts of thin-walled cells (sieve cells and parenchyma cells) produced when high levels of bark are pulped could result in paper machine drainage problems. Also to be considered when bark levels of 10-15% are being pulped are the economics of such factors as lower pulp yields, higher permanganate number and higher chemical consumption. Major losses have been described when daily production is reduced by 10% because the mill is "digester-limited" and pulp production is decreased as a result of pulping wood/bark mixtures [Keays and Hatton (52)].

The fiber content of hardwood bark offers an interesting situation when some type of mechanical procedure is used to break up and remove the bark. The part of the bark that does not respond to this type of treatment is usually the stringy, fiber-rich bark. As a result, a procedure that removes much of the non-fibrous bark (usually outer bark) and retains for pulping the stringy bark that behaves like wood during mechanical treatment, could result in a fairly favorable fiber yield situation. White ash, black tupelo, yellow poplar, quaking aspen, eastern cottonwood and shagbark hickory are examples of species that have been examined that could be a source of modest amounts of bark fiber.

There has been no consistent pattern with regard to level of bark extractives with the exception that the levels in the bark are from about three to eight times as high as in the wood. Most conifer barks have higher levels of extractives than do hardwood barks. Red pine and the southern pines (slash, loblolly, shortleaf, longleaf, and Virginia) are the exception with extractives levels from only 5.8 to 8.8%. Aspen and white birch are two hardwood species with high levels of extractives and Engelmann spruce and balsam fir are the two conifers with the highest levels of extractives. Even with these latter four species, because of the relatively thin bark involved, pitch problems are not expected to be serious unless, as the result of concentrating large amounts of bark from screening procedures, high levels of bark are pulped.

Wood/bark adhesion during the growing season was low and very similar for all species investigated (except sweetgum). Quite consistently, the zone of failure occurred in the cambium zone or the newly formed nonlignified wood fibers adjacent to the cambium zone. Dormant season adhesion was, as expected, higher than growing season adhesion and the failure zone usually occurred in the partially mature sieve and parenchyma cells of the inner bark, just outside the cambium zone. Dormant season wood/bark adhesion tends to be slightly higher for hardwoods than for conifers and, in certain instances, seems to be associated with the presence of large numbers of phloem fibers in the inner bark. Medium-high dormant season adhesion was associated with intermediate levels of inner bark fibers in aspen, cottonwood, and black tupelo. High wood/bark adhesion was associated with high levels of inner bark fibers in yellow poplar, white ash and shagbark hickory. Moderate levels of wood/bark adhesion in white birch and sycamore appear to be exceptions to the rule.

As discussed in Progress Report Four, breaking the bond between wood and bark (separation) is an important first step in any segregation procedure. A very practical way of separating bark and wood during the growing season, and in some instances during the dormant season, is through the action of the chipper. Arola

(53), working with northern hardwoods, found that chipper action during the growing season gave better results than during the dormant season with less than 2% bark remaining on the chips from 4-6 and 8-inch diameter bolts. Erickson (54) obtained similar results for spruce, balsam fir and jack pine. Results during the growing season were good; however, separation during the dormant season was poor (36-72%) for bolewood and even less for the thin-barked branchwood, with the poorest month of separation being November (36-48%). Erickson (54), working with maple, reported 96% separation during the chipping throughout the year. He also found better separation with winter-cut frozen wood over unfrozen bolts, although more fines resulted.

Despite the fairly consistent location of the wood/bark failure zone, there are, particularly in the dormant season, major differences between species in the ability of the chipper to cause separation. Preliminary Institute of Paper Chemistry investigations suggest inner bark strength and chipper knife impact on the cambium zone are important factors. For hardwoods, and possibly some conifers, the presence of fibers and sclereids in the inner bark influence inner bark strength. Bark thickness and wood density (or frozen wood) influence chipper knife impact at the cambium zone. Chipper separation during the dormant season is expected to be least effective on thin-bark, low-density woods with fiber in the inner bark. White spruce, although it has no fiber in the inner bark, is an example of a thin-barked, low density wood in which dormant season separation is poor.

Mechanical treatment of bark continues to look promising as a method of upgrading low-quality chips high in levels of bark. The approach attempts to take advantage of the lower strength and toughness of bark with the result that there will be a reduction in the size of the bark particles sufficient to allow removal by screening. For hardwoods, when a hammermilling type action is employed, the good bark removal seems to be best correlated with high specific gravity. For conifers, correlations between bark removal and bark toughness and/or strength are quite low. However when all three factors are considered (specific gravity, toughness and strength), fairly logical relationships are evident. Bark thickness in some instances also seems to be a factor influencing the effectiveness of hammermilling procedures. The most effective reduction in bark levels, particularly with hardwoods, results when specific gravity is high, bark strength and toughness is low and the bark is relatively thick. When inner bark strength is high because of high levels of bark fibers, the stringy inner bark reacts like wood and is retained with the wood. Although such inner bark is classified as bark contamination, modest levels should have no adverse influence on paper properties.

Chip shredding is a technique that was developed about twenty years ago and has been used mainly with conifers that are cooked by the kraft pulping process. As described in Progress Report Five, (page 119), at least two pieces of commercial equipment have been used in shredding investigations (Jones Vertiflex and Sprout-Waldron milling machines).[1] Shredded wood chips have been described as giving increased yields, lower chemical consumption and either reduced cooking temperature and/or cooking times (50,51). As described in Progress Report Six, chip shredding was tried using a relatively high moisture content red pine sample. Using a procedure that involves retaining the material on two and four-mesh screens and using for fuel the material that was retained on or passed through the ten-mesh screen resulted in a 9% wood loss and a chip sample still containing 8% bark.[2]

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[1]The Jones Vertiflex is manufactured by the Jones Division of the Beloit Corporation and the Sprout Waldron milling machine is produced by Sprout Waldron & Co., Inc.

[2]This information is slightly different than reported earlier because of a need to recalculate the results because of additional information obtained on the original bark input.

The results were not unexpected considering the hammermilling results and the available information on bark specific gravity, toughness and strength. Some improvement appeared possible if the moisture content had been reduced prior to shredding.

There are several tree species, based on their bark characteristics, that could be expected to behave in a manner similar to red pine. There are also a number of species in which shredding may be a viable alternative in view of the potential of this approach to reduce grit levels. With this in mind, a sample of northern white oak was shredded. Northern white oak has a high wood and bark specific gravity, moderate bark toughness and strength, and was expected to be a species that could be processed with a resulting good reduction in bark levels. As described earlier in this report, the end result was a 5% wood loss and a bark contamination level of just 6%. These results look quite promising in view of the fact that the treatment has the potential for grit removal, much of the retained bark has a reasonable fiber content and the discarded material is a valuable energy source.

Bark ash content, and calcium in particular, is of importance because of its apparent influence on recovery system scaling problems. Levels of ash, (and calcium) in the barks of conifers are quite consistently less than in hardwood bark. White spruce, yellow poplar and white birch are exceptions. Calcium levels range from 0.2% in longleaf, slash, loblolly and Ponderosa pine to 5.2% in northern white oak. Since the levels in the bark are about 10-15 times as high as in the wood of most hardwood pulp species, pulping of whole-tree chips can be expected to increase recovery system scaling problems.

The fuel values of the bark of all pulpwood species investigated are summarized in this report. The ovendry Btu values for hardwoods vary more than for conifers. Our data for hardwood bark confirms Chang and Mitchell's (32) observations and indicate that there is a negative correlation between ash content and ovendry Btu values. This relationship is less evident for the conifers investigated. Both hardwood and conifer barks, when the Btu values are converted to a cubic foot basis, demonstrate fairly major differences. These differences are due to bark specific gravity differences. Values range from 152,780 for red pine and 162,500 for cottonwood to 365,800 Btu/cubic ft. for southern red oak. Western larch also had a relatively low value for a conifer (176,500 Btu/cubic ft.) while Virginia pine had the highest value (309,000 Btu/cubic ft.).

PLANS

To date, the bark of 28 pulpwood species has been characterized, including quaking aspen, sugar maple, white birch, northern red oak (Report One); loblolly pine, slash pine, Douglas-fir, western hemlock (Report Two); white spruce, balsam fir, jack pine, eastern cottonwood (Report Three); southern white oak, northern white oak, southern red oak, sweetgum (Report Four); lodgepole pine, ponderosa pine, Engelmann spruce, western larch (Report Five); red pine, shortleaf pine, longleaf pine and Virginia pine (Report Six); and sycamore, yellow poplar, black tupelo and white ash (Report Seven). Four species remain to be characterized, using the regular format. These include black spruce, red alder, black cottonwood and silver maple. The report for these species is scheduled for completion around the end of January. We have tentative plans to characterize two additional species, western red cedar and shagbark hickory, which are unique because they contain high amounts of bark fiber. In addition, we plan to summarize, in a special report, the findings of the bark characterization research.

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GLOSSARY

Basic density. Green weight divided by green volume.

Cambium. A cylinder, strip, or layer of meristematic cells, which divide to give cells which ultimately form a permanent tissue. The primary cambium in the stem and root gives rise to xylem and phloem, and the secondary one produces bark.

dbh. Diameter breast height (4.5 feet).

Gelatinous fiber. Fiber, the inner wall of which is more or less gelatinous, or jellylike.

Inner bark. Tissues in the cylindrical axis of a tree immediately outside the cambium; includes the region of the secondary phloem from the cambium to the last-formed periderm.

Outer bark. Tissues in the cylindrical axis of a tree immediately outside the inner bark; includes the tissues from the last-formed periderm to the outer surface of the bark.

Paratracheal. Said of xylem parenchyma which occurs at the edge of the annual ring, around the vessels, but nowhere else.

Parenchyma. Tissue consisting of short, relatively thin-walled cells, generally with simple pits; concerned primarily with storage and distribution of carbohydrates.

Periderm. Term applied to the cork cambium (phellogen) and the tissues (phellem and phelloderm) derived from the cork cambium.

Ray. Ribbon-shaped strand of tissue extending in a radial direction across the grain.

Resin canal. An intercellular space, often bordered by secreting cells, containing resin or turpentine.

Rhytidome. A tissue cut off outside a periderm. The cells die leaving a crust made up of alternate layers of cork and dead phloem or cortex.

Scalariform. Like a ladder.

Sclereid. See Sclerenchyma.

Sclerenchyma. Mechanical tissue consisting of cells with thick, lignified walls and small lumens. If the cells are elongated, they are called fibers and usually occur in bundles. When the cells are oval or rounded, they are called sclereids. They occur singly or in groups.

Secondary phloem. Inner bark.

Segregation. Removal of either the wood or bark fraction from wood/bark chip mixtures.

Separation. Detachment of bark from wood.

Sieve tube. A characteristic element of phloem. It translocates food materials synthesized in the plant. The cells are living, thin-walled and in longitudinal rows. They are connected by perforations in their transverse walls, through which pass strands of cytoplasm.

Specific gravity. Ovendry weight divided by green volume unless otherwise specified.

Storied. Arranged in tiers or in echelon, as viewed on a tangential surface or in a tangential section.

Suberized. Transformed into cork.

Tracheid. Fibrous lignified cell with bordered pits and imperforate ends; in coniferous wood, the tracheids are very long (up to 7+ mm) and are equipped with large, prominent bordered pits on their radial walls; tracheids in hardwoods are shorter fibrous cells (seldom over 1.5 mm), are as long as the vessel segments with which they are associated, and possess small bordered pits.

Tylose. A balloonlike enlargement of the membrane of a pit in the wall of a vessel or tracheid, and a xylem parenchyma cell lying next to it. It protrudes and blocks the cavity of the wood element.

Uniseriate. Arranged in a single row, series, or layer. Also said of a vascular ray which is one cell wide in cross section.

Vasicentric. Paratracheal.

Vessel. Composite, and hence articulated, tubelike structure found in porous wood, arising through the fusion of the cells in a longitudinal row through the partial or complete disappearance of the cross walls.

Xylary initials. The newly formed vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support.

Xylem. Wood. The vascular tissue which conducts water and mineral salts throughout the plant and provides mechanical support. It consists of vessels, and/or tracheids, fibers and some parenchyma.

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APPENDIX

TABLE XXXI

SAMPLE TREE INFORMATION

Species	Tree No.	Age, yr	Height, ft	dbh, inch	Location
Sycamore	3212-110	36	65	9.3	Garland Co., Arkansas
	3212-114	28	--	8.4	Murfreesboro, North Carolina
Yellow poplar	3212-102	51	74	8.4	Norris, Tennessee
	3212-103	54	67	8.8	Norris, Tennessee
Black tupelo	3212-111	28	48	7.1	Garland Co., Arkansas
	3212-115	36	--	8.0	Murfreesboro, North Carolina
White ash	3212-112	70	60	7.9	Door Co., Wisconsin
	3212-113	71	68	7.6	Door Co., Wisconsin

TABLE XXXII

BETWEEN-SPECIES COMPARISONS OF WOOD/BARK ADHESION

Species	Wood/Bark Adhesion, kg/cm^2 Peeling Season	Dormant Season
Loblolly pine	5.8	5.5
Slash pine	3.5	9.1
Douglas-fir	3.4	8.0
Western hemlock	3.6	8.2
White spruce	4.4	10.3
Jack pine	4.0	10.7
Balsam fir	2.4	9.0
Lodgepole pine	2.2	5.6
Ponderosa pine	5.0	9.6
Engelmann spruce	3.4	12.5
Western larch	1.2	4.4
Red pine	--[a]	9.6
Shortleaf pine	--[a]	8.6
Longleaf pine	--[a]	22.0
Virginia pine	--[a]	7.2
Shagbark hickory	5.3	26.9
Eastern cottonwood	4.4	13.5
Quaking aspen	6.4	11.4
Bur oak	5.8	9.6
White birch	5.1	12.0
Sugar maple	5.8	10.1
Northern red oak	2.5	8.4
Southern red oak	5.4	8.2
Northern white oak	4.8	7.8
Southern white oak	--[a]	7.2
Sweetgum	10.2	15.3
Sycamore	--[a]	14.8[b]
Yellow poplar	--[a]	16.6
Black tupelo	--[a]	13.5
White ash	--[a]	23.8

[a]Growing season adhesion not measured.
[b]Samples failed in tensile.

TABLE XXXIII

BETWEEN-SPECIES COMPARISONS OF BARK STRENGTH

Species	Bark Strength kg/cm² Inner Bark	Outer Bark
Loblolly pine	3.7	3.2
Slash pine	6.4	5.2
Douglas-fir	5.8	3.0
Western hemlock	6.0	--
White spruce	--	7.4
Jack pine	2.3	2.3
Balsam fir	1.7	1.4
Lodgepole pine	--	2.4
Ponderosa pine	4.6	4.9
Engelmann spruce	--	4.2
Western larch	4.5	4.4
Red pine	--	5.6
Shortleaf pine	7.4	2.7
Longleaf pine	--	5.8
Virginia pine	4.6	4.0
Shagbark hickory	25.0	72.7
Eastern cottonwood	17.7	4.2
Quaking aspen	9.0	4.9
Bur oak	4.5	7.0
White birch	1.6	9.8
Sugar maple	1.4	4.7
Northern red oak	2.1	4.6
Southern red oak	3.6	3.4
Northern white oak	4.6	3.2
Southern white oak	4.7[a]	--
Sweetgum	8.1	5.2
Sycamore	6.1	--
Yellow poplar	13.4	10.4
Black tupelo	9.6	10.5
White ash	20.0	4.2

[a]Bark strength measured on total bark rather than inner and outer bark.

TABLE XXXIV

MODULUS OF ELASTICITY VALUES[a]
SOFTWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
White spruce	1	20600	--	12200
	2	29600	--	17300
Jack pine	1	25700	--	4400
	2	24600	--	3800
Loblolly pine	1	25200	6700	3800
	2	21200	6500	2100
Western hemlock	1	43300	12600	7000
	2	34900	13200	4400
Douglas-fir	1	42400	28200	--
	2	43100	21700	1000
Slash pine	1	33100	3400	1900
	2	29800	3300	1900
Balsam fir	1	35200	6200	--
	2	21600	7000	--
Engelmann spruce	1	21600	24500	--
	2	30000	25500	6700
Ponderosa pine	1	15200	6500	2000
	2	34800	5100	3700
Lodgepole pine	1	30100	6700	1900
	2	24700	25900	5300
Western larch	1	40900	10900	5300
	2	40800	31600	8100
Red pine	1	18600	25800	1800
	2	20000	28900	3100
Shortleaf pine	1	35900	14300	3100
	2	41800	25000	3800
Virginia pine	1	48100	37100	3700
	2	23000	30700	7800
Longleaf pine	1	49500	33900	3800
	2	42000	26200	5900

[a]Values based upon 4-6 determinations except the outer bark for western hemlock tree #2 which is one determination. Dashes indicate bark was unable to be tested for various reasons.

TABLE XXXV

MODULUS OF ELASTICITY VALUES[a]
HARDWOODS
kg/cm^2

Species	Tree No.	Wood	Bark Inner	Bark Outer
Northern white oak	1	19100	10400	6700
	2	42800	6700	2700
Sugar maple	1	31600	14000	3500
	2	43600	15900	3300
Quaking aspen	1	17000	14000	6500
	2	24400	8200	--
Northern red oak	1	23700	13500	10900
	2	34100	6800	7800
White birch	1	34200	6900	1900
	2	33400	8400	2200
Eastern cottonwood	1	33900	23200	4300
	2	48700	17900	7200
Silver maple	1	31500	32000	13900
	2	32600	25000	11500
Sweetgum	1	23400	21300	--
	2	32700	23400	13400
Southern red oak	1	45500	10700	8600
	2	36500	7400	5900
Southern white oak	1	52000	6900	4700
	2	41000	9700	5500
Black tupelo	1	39000	9400	--
	2	41300	15700	--
Sycamore	1	43300	9600	--
	2	30000	12100	--
Yellow poplar	1	35800	11000	7400
	2	22800	8800	7500
White ash	1	47600	15500	7100
	2	50400	19500	8200

[a]Values based upon 4-6 determinations. Dashes indicate bark was unable to be tested for various reasons.